DEVELOPMENT OF A WATER TEMPERATURE MODEL RELATING PROJECT OPERATIONS TO COMPLIANCE WITH THE WASHINGTON STATE AND EPA WATER QUALITY STANDARDS
(Water Temperature Study)

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

FINAL REPORT
REQUIRED BY FERC

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ABSTRACT

To assess compliance with the State temperature standards, two 2D laterally-averaged temperature models (using CE-QUAL-W2) were developed that represent existing (or “with Project”) conditions and “without Project” conditions of the Wells Project including the Columbia River from the Chief Joseph Dam tailrace to Wells Dam, the lowest 15.5 miles of the Okanogan River, and the lowest 1.5 miles of the Methow River. The results were processed to develop daily values of the seven-day average of the daily maximum temperatures (7-DADMax), and then compared for the two conditions.

The model analyses demonstrated that “with Project” temperatures in the Columbia, Okanogan and Methow rivers do not increase more than 0.3^{o}C compared to ambient (“without Project”) conditions anywhere in the reservoir, and that the Project complies with state water quality standards for temperature. The analyses also show that backwater from the Wells Project can reduce the very high summer temperatures observed in the lower Okanogan and Methow rivers. The intrusion of Columbia River water into the lowest 1-2 miles of the Okanogan River and lowest 1.5 miles of the Methow River can significantly decrease the temperature of warm summer inflows from upstream, and can also moderate the cold winter temperatures by 1-3^{o}C, reducing the extent and length of freezing.

1.0 INTRODUCTION

1.1 General Description of the Wells Hydroelectric Project

The Wells Hydroelectric Project (Wells Project) is located at river mile (RM) 515.6 on the Columbia River in the State of Washington (Figure 1.1-1). Wells Dam is located approximately 30 river miles downstream from the Chief Joseph Hydroelectric Project, owned and operated by the United States Army Corps of Engineers (COE); and 42 miles upstream from the Rocky Reach Hydroelectric Project owned and operated by Public Utility District No. 1 of Chelan County (Chelan PUD). The nearest town is Pateros, Washington, which is located approximately 8 miles upstream from the Wells Dam.

The Wells Project is the chief generating resource for Public Utility District No. 1 of Douglas County (Douglas PUD). It includes ten generating units with a nameplate rating of 774,300 kW and a peaking capacity of approximately 840,000 kW. The design of the Wells Project is unique in that the generating units, spillways, switchyard, and fish passage facilities were combined into a single structure referred to as the hydrocombine. Fish passage facilities reside on both sides of the hydrocombine, which is 1,130 feet long, 168 feet wide, with a crest elevation of 795 feet in height.

The Wells Reservoir is approximately 30 miles long. The Methow and Okanogan rivers are tributaries of the Columbia River within the Wells Reservoir. The Wells Project boundary extends approximately 1.5 miles up the Methow River and approximately 15.5 miles up the Okanogan River. The surface area of the reservoir is 9,740 acres with a gross storage capacity of 331,200 acre-feet and usable storage of 97,985 acre feet at the normal maximum water surface elevation of 781 above mean sea level (msl) (Figure 1.1-1).

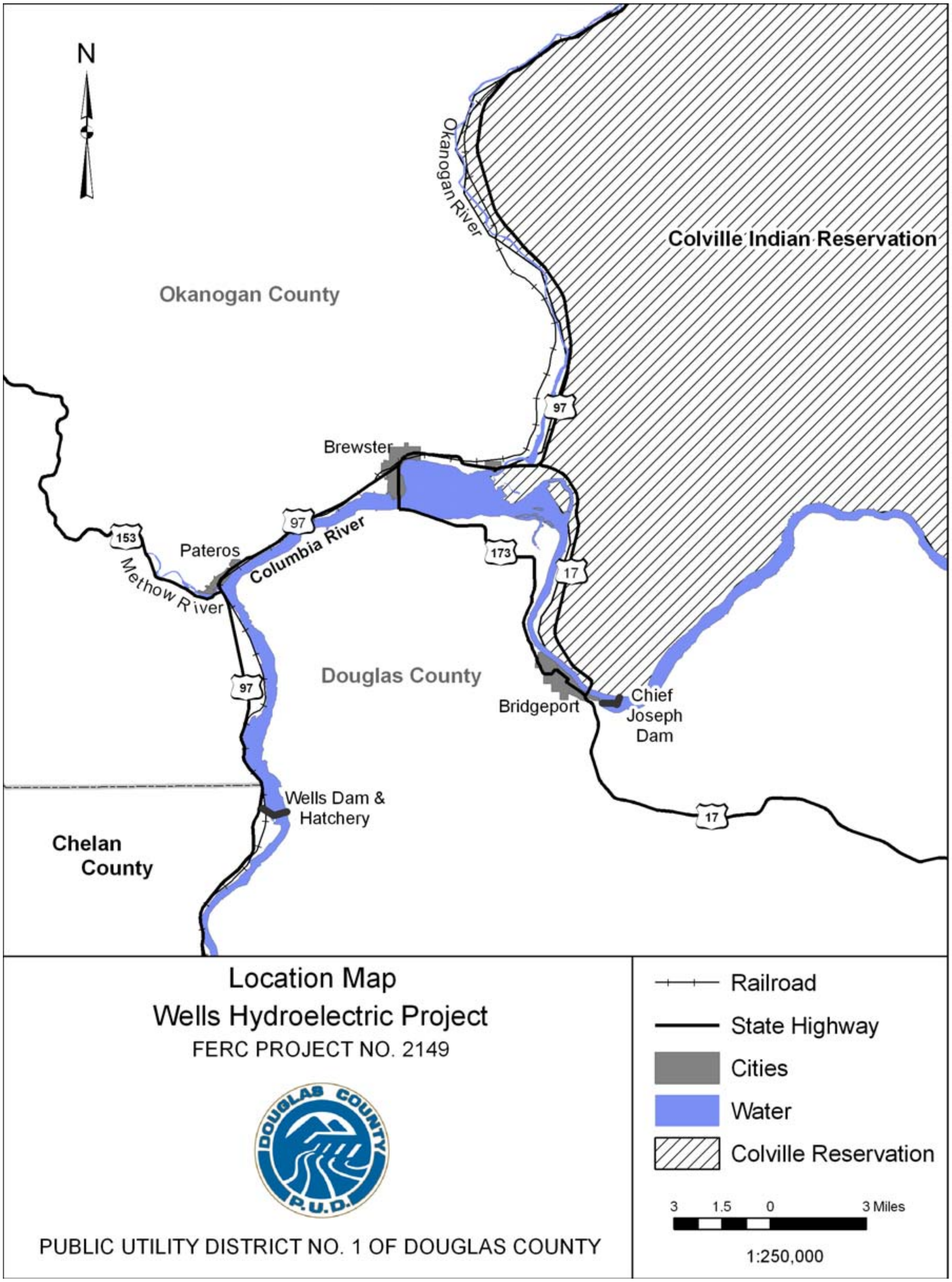

Figure 1.1-1 Location Map of the Wells Project

1.2 Relicensing Process

The current Wells Project license will expire on May 31, 2012. Douglas PUD is using the Integrated Licensing Process (ILP) promulgated by Federal Energy Regulatory Commission (FERC) Order 2002 (18 CFR Part 5). Stakeholders consisting of representatives from state and federal agencies, tribes, local governments, non-governmental organizations and the general public have participated in the Wells Project ILP, from a very early stage, to identify information needs related to the relicensing of the Wells Project.

In August 2005, Douglas PUD initiated a series of Resource Work Group (RWG) meetings with stakeholders regarding the upcoming relicensing of the Wells Project. This voluntary effort was initiated to provide stakeholders with information about the Wells Project, to identify resource issues and to develop preliminary study plans prior to filing the Notice of Intent (NOI) and Pre-Application Document (PAD). The RWGs were formed to discuss issues related to the Wells Project and its operations.

The primary goals of the RWGs were to identify resource issues and potential study needs in advance of Douglas PUD filing the NOI and PAD. Through 35 meetings, each RWG cooperatively developed a list of Issue Statements, Issue Determination Statements and Agreed-Upon Study Plans. An Issue Statement is an agreed-upon definition of a resource issue raised by a stakeholder. An Issue Determination Statement reflects the RWGs' efforts to apply FERC's seven study criteria to mutually determine the applicability of each individual Issue Statement. Agreed-Upon Study Plans are the finished products of the informal RWG process.

Douglas PUD submitted the NOI and PAD to FERC on December 1, 2006. The PAD included the RWGs’ 12 Agreed-Upon Study Plans. The filing of these documents initiated the relicensing process for the Wells Project under FERC’s regulations governing the ILP.

On May 16, 2007, Douglas PUD submitted a Proposed Study Plan (PSP) Document. The PSP Document consisted of the Applicant’s Proposed Study Plans, Responses to Stakeholder Study Requests and a schedule for conducting the Study Plan Meeting. The ILP required Study Plan Meeting was conducted on June 14, 2007. The purpose of the Study Plan Meeting was to provide stakeholders with an opportunity to review and comment on Douglas PUD’s PSP Document, to review and answer questions related to stakeholder study requests and to attempt to resolve any outstanding issues with respect to the PSP Document.

On September 14, 2007, Douglas PUD submitted a Revised Study Plan (RSP) Document. The RSP Document consisted of a summary of each of Douglas PUD’s revised study plans and a response to stakeholder PSP Document comments.

On October 11, 2007, FERC issued its Study Plan Determination based on its review of the RSP Document and comments from stakeholders. FERC’s Study Plan Determination required Douglas PUD to complete 10 of the 12 studies included in its RSP Document. The FERC approved studies include the development of a water temperature model relating project operations to compliance with the Washington State and EPA water quality standards (Water Temperature Study). Douglas PUD has opted to complete all 12 studies to better prepare for the

401 Water Quality Certification process conducted by the Washington State Department of Ecology (Ecology) and to fulfill its commitment to the RWGs who collaboratively developed the 12 Agreed-Upon Study Plans with Douglas PUD. These study plans have been implemented during the designated ILP study period. The results from the study plans will be presented in 12 Study Reports. Each report will be included in Douglas PUD's Initial Study Report (ISR) Document, which is scheduled for filing with FERC on October 15, 2008.

There were no variances from the FERC approved study plan for the Water Temperature Study.

This report completes the Water Temperature Study.

2.0 GOALS AND OBJECTIVES

Consistent with the FERC approved study plan, the goal of the study is to develop two temperature models (using CE-QUAL-W2) to assess the effects of Wells Project operations on water temperatures at Wells Dam and within the Wells Reservoir as they relate to compliance with the Washington State Water Quality Standards and Section 401 of the Clean Water Act certification process.

Ecology is the agency responsible for administering the State Water Quality Standards and for the issuance of Section 401 water quality certificates for hydroelectric relicensing processes in Washington. The information gathered from this modeling effort will assist Ecology in determining if, and to what extent the Project's operations affect water temperature in excess of the narrative and/or numeric criteria.

3.0 STUDY AREA

The study area is defined as the waters within the Wells Reservoir. This consists of the mainstem Columbia River upstream of Wells Dam to the tailrace of Chief Joseph Dam (RM 544.5), and the Okanogan (to RM 15.5) and Methow (to RM 1.5) rivers within Project boundary (Figure 1.1-1).

4.0 BACKGROUND AND EXISTING INFORMATION

In preparation for the development of a temperature model, Douglas PUD assessed the suite of models available. The CE-QUAL-W2 model (W2 model) is widely used to support the establishment of total maximum daily loads (TMDLs) for Washington waters, and is a generally accepted model for evaluating the effects of hydroelectric projects. Therefore, the W2 model was considered the basis for making decisions regarding data needs and data archiving. With guidance from consultants having expertise in water quality modeling, Douglas PUD conducted a review of the types of information being collected within the Wells Project and whether the data currently collected was sufficient to support W2 model development. Based on this data review, Douglas PUD modified existing monitoring programs and in some cases initiated new programs in order to collect the necessary information for the W2 model.

Flow Data

Water flowing into the Wells Project originates from Chief Joseph Dam, on the Columbia River, and from the Okanogan and Methow rivers. Continuous hourly flow data from Chief Joseph Dam, located upstream of Wells Dam, are available from the Columbia River Operational Hydromet Management System (CROHMS) database. A stream gauge station located near the town of Malott, WA, measures flow in the Okanogan River at RM 17.0 (USGS Gauge No. 12447200). The Malott USGS stream gauge is located 1.5 miles upstream of the Wells Project boundary on the Okanogan River. A stream gauge station located near Pateros measures flow in the Methow River (USGS Gauge No. 12449950) at the point where the river enters the Wells Project. All three of the boundary water monitoring stations provides Douglas PUD with hourly flow data.

Water flowing out of the Wells Project must first pass through Wells Dam. Douglas PUD collects and records hourly flow data for the water passing through the turbines, spillways and adult fish ladders at Wells Dam. Additionally, there is a United States Geological Survey (USGS) gauging station downstream of Wells Dam that also collects river flow information and is representative of water passing through Wells Dam.

Temperature Data

Beginning in 2001, an extensive water temperature monitoring effort was initiated to establish the temperature dynamics throughout the Wells Reservoir. Temperature data were collected at seven locations: the Columbia River at RM 544, RM 532, RM 530, and RM 516; at RM 1.5 in the Methow River; and at RM 10.5 (Wakefield Bridge) and RM 1.3 (SR 97 Bridge) in the Okanogan River. Data were collected hourly using Onset TidbiT temperature loggers. Monitoring start and end dates varied among years, but generally began in the spring and ended in late fall. Quality assurance and control measures were implemented prior to deploying and upon retrieving temperature loggers, to ensure that data collected were accurate (Douglas PUD, 2005). Data at some of these monitoring locations were infrequently discontinuous due to sensor loss or malfunction in some years.

An additional component of the water temperature monitoring effort initiated in 2001 was to measure vertical temperature profiles at the RM 516 location in the Columbia River in the Wells Dam forebay. The temperature station was located along the east portion of the forebay, in what had been the original channel of the Columbia River prior to the construction of the Wells Project. Each year between 2001 and 2005, temperature loggers were deployed at three different depths between 5 and 90 feet, approximately 30 feet apart. Results showed no measurable thermal stratification and reflected the limited storage capacity of the Wells Reservoir.

Starting in 2006 and following the completion of the data review and data gap analysis, Douglas PUD expanded the Wells Reservoir temperature monitoring season to cover the entire year and implemented a more frequent downloading schedule to avoid temperature data gaps. Douglas PUD also added additional monitoring stations at the mouths of the Okanogan (RM 1.3) and Methow (RM 0.1) rivers. Collectively, these data documented the incoming water temperatures to the Wells Project (boundary conditions), as well as other sites throughout the Wells Reservoir including the Wells Dam forebay, and were integral to the development of the W2 temperature models.

Meteorological Data Collection

Site specific weather information is an essential component of water temperature models. Weather information characteristic of the entire Wells Reservoir was unavailable until 2005 when Douglas PUD began collecting site specific meteorological data. Douglas PUD identified three sites that would most effectively characterize the weather trends in the Wells Reservoir at Chief Joseph Dam (upper reservoir area), Bridgeport Bar (mid-reservoir area) and the Wells Project forebay (lower reservoir area). Since reliable meteorological information was already available near Chief Joseph Dam, NRG Systems weather stations were erected at the other two identified sites in order to collect parameters required to support water temperature modeling. The parameters collected were air temperature, relative humidity, dew point temperature, solar incidence, wind speed, and wind direction.

Bathymetric Data Collection

In March 2005, Douglas PUD contracted with GeoEngineers to conduct a detailed bathymetric survey of the Wells Reservoir and tailrace using multibeam sonar and Global Positioning System (GPS) technology. Contour maps of the reservoir bottom were produced at 1-foot contour intervals, and a digital elevation model (DEM) was produced at a pixel resolution of 10-feet. The DEM provides a seamless representation of the riverbed surface.

4.1 Aquatic Resource Work Group

As part of the relicensing process for the Wells Project, Douglas PUD established an Aquatic Resource Work Group (RWG) which began meeting informally in November, 2005. This voluntary effort was initiated to provide stakeholders with information about the Wells Project, to collaboratively identify potential resource issues related to Project operations and relevant to relicensing, and to develop preliminary study plans to be included in the Wells Pre-Application Document (PAD)(DCPUD 2006).

Through a series of meetings, the Aquatic RWG cooperatively developed a list of Issue Statements, Issue Determination Statements and Agreed-Upon Study Plans. An Issue Statement is an agreed-upon definition of a resource issue raised by a stakeholder. An Issue Determination Statement reflects the RWG’s efforts to review the existing project information and to determine whether an issue matches with FERC's seven criteria and would be useful in making future relicensing decisions. Agreed-Upon Study Plans are the finished products of the informal RWG process.

Based upon these meetings and discussions, the Aquatic RWG proposed to conduct a study to evaluate the effect of Project operations on compliance with temperature standards in the Wells Project (6.2.1.6). The need for this study was agreed to by all of the members of the Aquatic RWG, including Douglas PUD. This study will help to inform future relicensing decisions and will fill data gaps that have been identified by the Aquatic RWG.

The Issue Statement and Issue Determination Statement listed below were included in the PAD (section number included) filed with FERC on December 1, 2006:

4.1.1 Issue Statement (PAD Section 6.2.1.6)

Project operations may affect compliance with temperature standards in the Wells Project.

4.1.2 Issue Determination Statement (PAD Section 6.2.1.6)

The Wells Project can have an effect on compliance with the water temperature standard. The Aquatic Resource Work Group members agree that studies to address this issue are feasible and the results will be meaningful for the 401 Water Quality Certification Process. Douglas PUD is currently collecting temperature data throughout the Wells Project. Furthermore, Douglas PUD has established weather stations to collect meteorological data in key locations of the Wells Reservoir. These data sets will be utilized to develop a temperature model (i.e., CE-QUAL-W2) to assess the Wells Project's effect on water temperatures.

The Resource Work Group believes that a study to develop a temperature model is necessary to determine compliance with the state's water quality standards. The resource work group agrees that this study (development of specific water temperature models) should be implemented during the two-year ILP study period.

Toward this goal, Douglas PUD will continue to collect water temperature and meteorological data during 2006 and 2007 for use in the development of a temperature model to be used in 2008 and/or 2009. Data may continue to be collected in 2008 and 2009, if necessary.

4.2 Project Nexus

Ecology is responsible for the protection and restoration of the state's waters. Ecology has adopted standards that set water quality criteria for lakes, rivers, and marine waters in order to protect water quality and dependent uses. Ecology's current (2006) water quality standards classify fresh water by use, rather than by class, as was done in earlier standards. Those most pertinent to the Project are:

For the tributary reaches that are within the Wells Project boundary (Okanogan River from RM 0 to RM 15.5 and the Methow River from RM 0 to RM 1.5),

- Water temperature shall not exceed 17.5°C (63.5°F), where water temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax);
- When a water body's temperature is warmer than 17.5°C (or within 0.3°C (0.54°F) of 17.5°C) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F);
- When the natural condition of the water is cooler than 17.5°C, the incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F);

- The Methow River within the Project boundary (RM 0 to RM 1.5) has been identified by Ecology as a requiring special protection for salmon and trout spawning and incubation. From October 1st to June 15th, water temperature shall not exceed 13.0°C, as measured by the 7-DADMax.

For the mainstem Columbia River that is within the Wells Project boundary,

- Water temperature shall not exceed 17.5°C (64.4°F), where water temperature is measured by the 7-DADMax;
- When a water body's temperature is warmer than 17.5°C (or within 0.3°C (0.54°F) of 17.5°C) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F);
- When the natural condition of the water is cooler than 17.5°C, the incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F).

Water flowing into and through the Wells Reservoir typically begins warming in March and reaches peak annual temperatures in August through early September. During this time period, incoming water to the Wells Project can exceed both the tributary and mainstem 7-DADMax numeric criteria of 17.5°C. A portion of the mainstem Columbia River encompassing Wells Dam is on the 2004 303(d) list as an impaired waterbody for temperature.

Water temperature is one of many environmental factors that may affect salmonid populations in the mid-Columbia River basin. Increasing temperature levels above a given threshold can cause upstream migration delays, promote disease, and increase the probability of mortality for salmonids at all life history stages. Natural ambient water temperatures often exceed lethal tolerance levels for salmonids in the lower Okanogan River (NMFS, 2002). Yet, the Okanogan watershed currently supports healthy runs of summer and fall Chinook salmon, the largest run of sockeye salmon in the Columbia Basin, and steelhead (NMFS, 2002).

5.0 METHODOLOGY

The W2 model is widely used to support the establishment of TMDLs for Washington waters and is a generally accepted model for evaluating the effects of hydroelectric projects on various water quality parameters (EES Consulting, 2006).

The development of a W2 model consists of two major components: data collection for model input and model development/implementation. The data collection component in W2 model development includes site review and field reconnaissance, data gap analyses, preliminary data collection design and implementation of data collection programs. The model development/implementation component consists of model input data preparation, model development, hydrodynamic and temperature calibration, sensitivity analyses, and hypothesis testing.

5.1 Model Data

Data for the W2 model of the Wells Project included bathymetry, flows, inflow water temperatures, meteorology, and in-reservoir temperatures for model calibration. Douglas PUD collected significant temperature data in the reservoir and meteorological data during 2006 and 2007.

5.1.1 Bathymetry

Douglas PUD collected high-resolution bathymetric data for the Project. GeoEngineers (2008) recently used these data to develop a one-dimensional, steady-flow HEC-RAS model (HEC, 2005) of the system. The cross sections from the HEC-RAS model were used to develop the W2 geometry file, supplemented by some additional sections cut from the ARC/GIS geometry files.

5.1.2 Flows, Stage, and Water Temperature

Water flowing into the Wells Project originates from Chief Joseph Dam on the Columbia River, and from the Okanogan and Methow Rivers. Continuous hourly flow data from Chief Joseph Dam, located upstream of Wells Dam, are available from the Corps of Engineers' Columbia River Operational Hydromet Management System (CROHMS) database. A stream gauge station located near the town of Malott, WA, measures flow and temperature in the Okanogan River (USGS Gauge No. 12447200) 1.5 miles upstream of the location where the Okanogan River enters the Wells Project. A stream gauge located near Pateros measures flow in the Methow River (USGS Gauge No. 12449950) at the point where the river enters the Wells Project. All three of the boundary water monitoring stations provided Douglas PUD with hourly flow data. Water flowing out of the Wells Project must first pass through Wells Dam. Douglas PUD collects and records hourly flow data for the water passing through the turbines, spillways and adult fish ladders at Wells Dam. Additionally, there is a USGS gauging station downstream of Wells Dam that also collects river flow information and measures the total flow of water passing through Wells Dam.

Input data to the model included flows and water temperatures at all upstream boundaries of the W2 model (Figure 5.1-1). Flow was defined at the downstream end of the "with" and "without" project models, respectively, allowing the W2 models to compute outflow temperatures. The model data were assembled from the gauges shown in Figure 5.1-2.

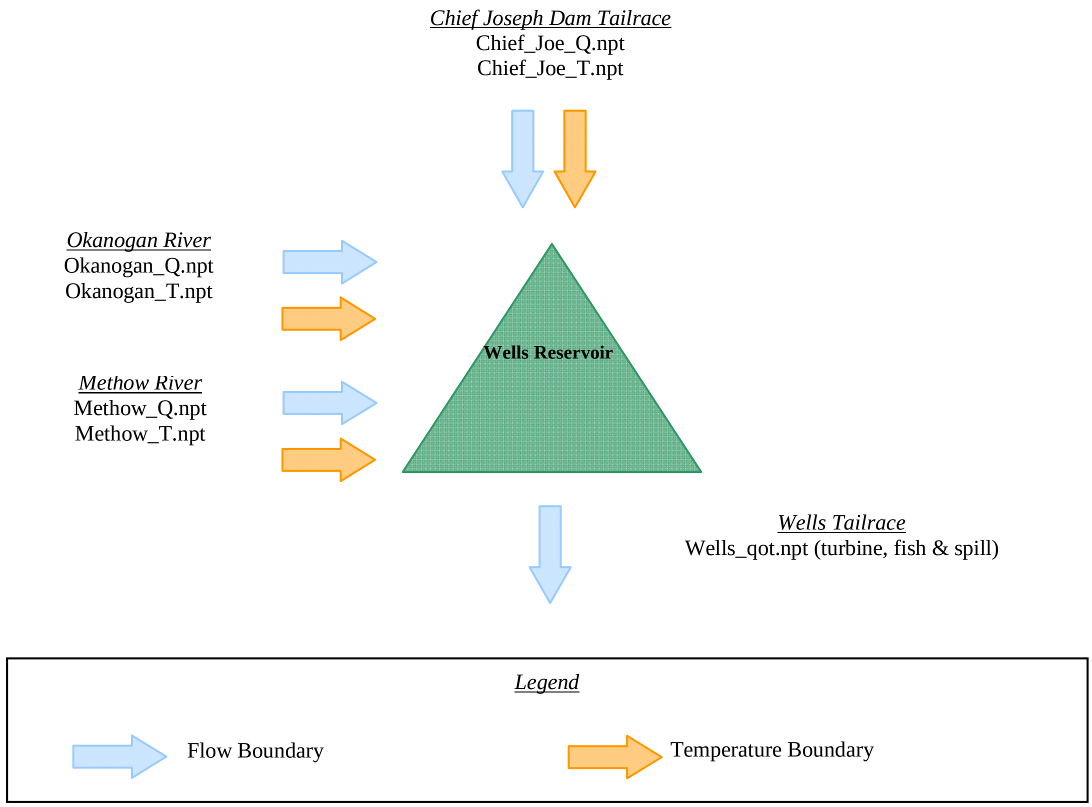

Figure 5.1-1 Schematic of W2 boundary conditions and file names.

Douglas PUD provided hourly flow data from the Chief Joseph Dam (Figure 5.1-3) and Wells Dam (Figure 5.1-4) for January 1, 2006 through December 31, 2007. Hourly streamflow data entering the Wells Project for the Okanogan River (Malott: USGS Gauge No. 12447200; Figure 5.1-5) and for the Methow River near Pateros (Pateros: USGS Gauge No. 12449950; Figure 5.1-6) were obtained from the USGS for January 1, 2006 through September 30, 2007. The flows in these figures are shown in "m^3/sec".

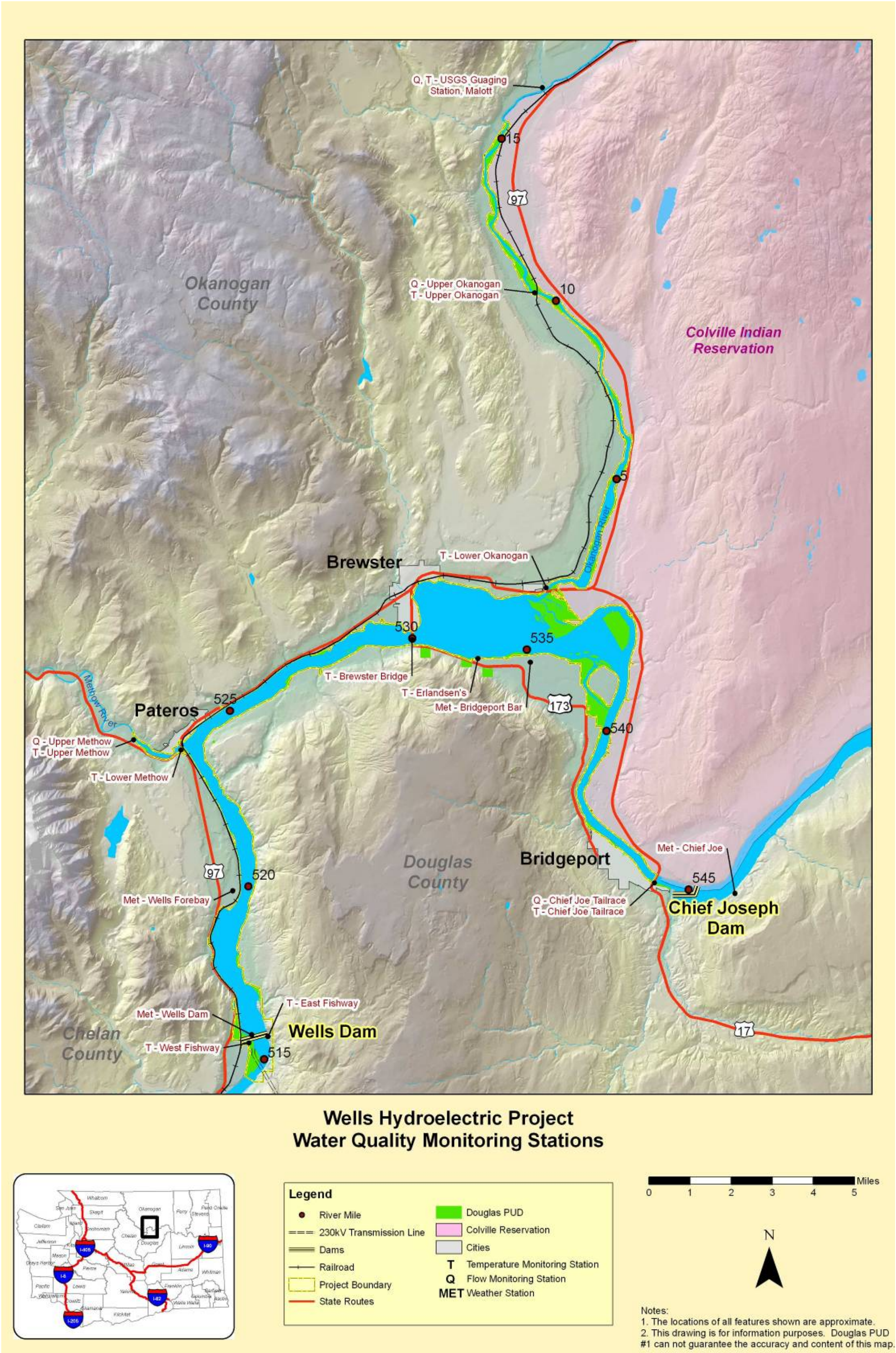

Figure 5.1-2 Location of stream gauges.

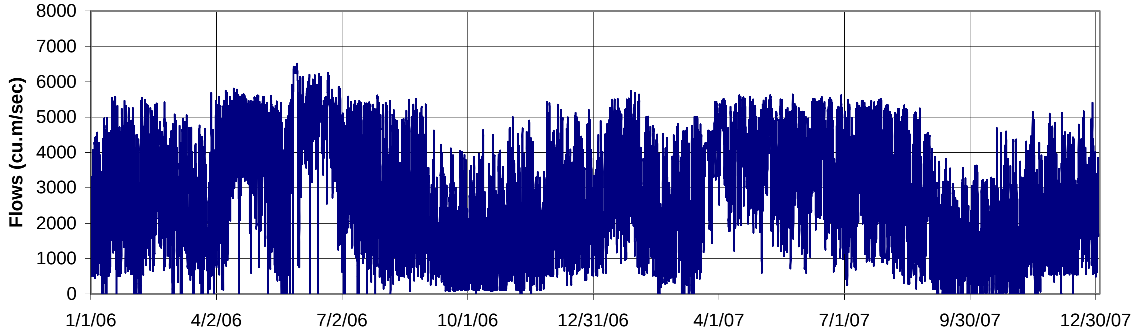

Figure 5.1-3 Chief Joseph Dam total hourly discharge.

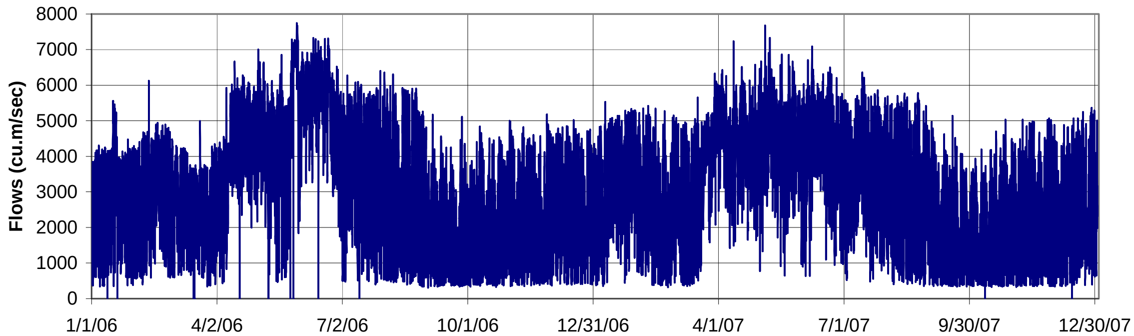

Figure 5.1-4 Wells Dam total hourly discharge.

Figure 5.1-5 Hourly Flows in Okanogan River at Malott.

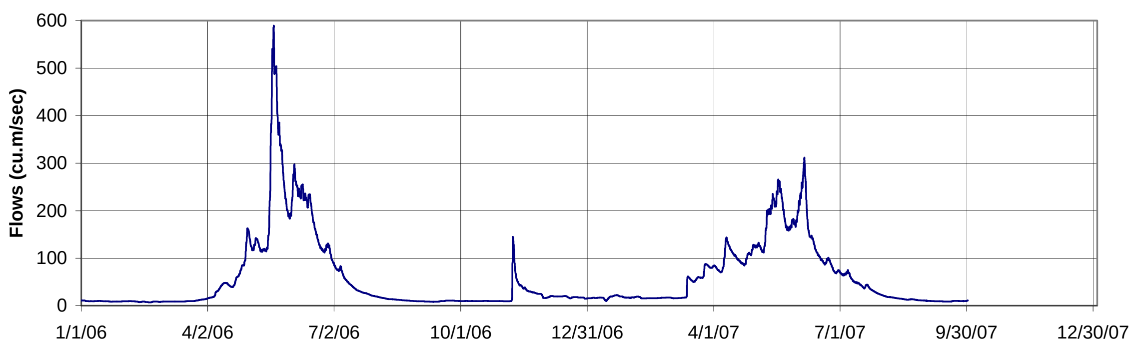

Figure 5.1-6 Hourly Flows in Methow River Near Pateros.

Reservoirs modeled using W2 generally use upstream inflows and downstream outflows. Therefore, it is important that these flows balance, otherwise the reservoir may rise or fall to unrealistic water surface elevations. Figure 5.1-7 shows the daily difference between the measured outflow from Wells Dam minus the measured total inflow to Wells Reservoir (Chief Joseph Dam, the Okanogan River, and the Methow River). This imbalance is not surprising. As with most flow measurements, the reported discharge values may have small measurement errors.

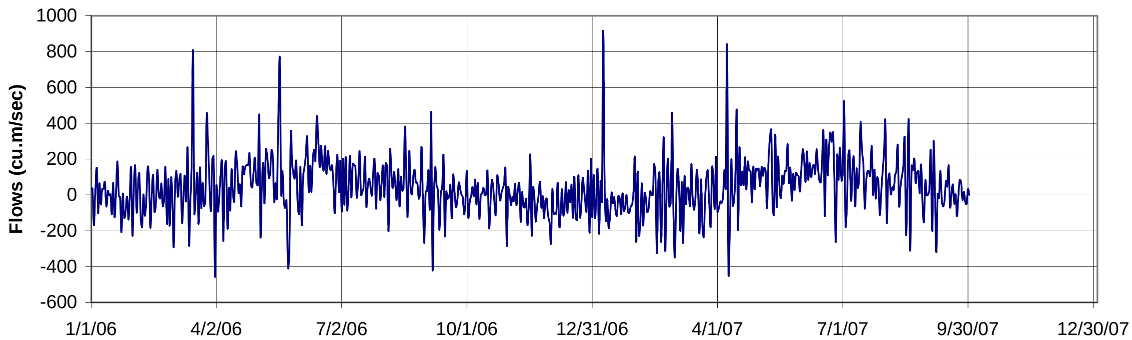

Figure 5.1-7 Difference between daily total outflow minus inflow.

Over the two-year period of model calibration data, the net imbalance, outflows minus inflows, is about 43 m^3/sec, or about one percent of average flows in the Columbia River. A "water balancing" approach was used to calculate the daily differences between outflows and inflows, including changes in reservoir storage, which were then added as a source distributed uniformly along the Columbia River. Figure 5.1-8 compares the observed stage in the Wells Forebay with the modeled stage. The agreement is reasonable given that the reservoir elevation changes little over the two-year period.

A review of the observed Wells forebay stage shows that the stage generally varies from 236.1 m (774.5 ft) to 238.1 m (781.0 ft), but the reservoir was lowered to 235.1 m (771.2 ft) during May 2006 in response to large inflows throughout the system. A stage of 237.4 m (778.8 ft) was exceeded 80% of the time; a stage of 237.7 m (779.8 ft) was exceeded 50% of the time; and a stage of 237.9 m (780.4 ft) was exceeded 20% of the time. These data demonstrate the extent to which the Wells Project maintains a near "run-of-the-river" condition with a steady water surface elevation.

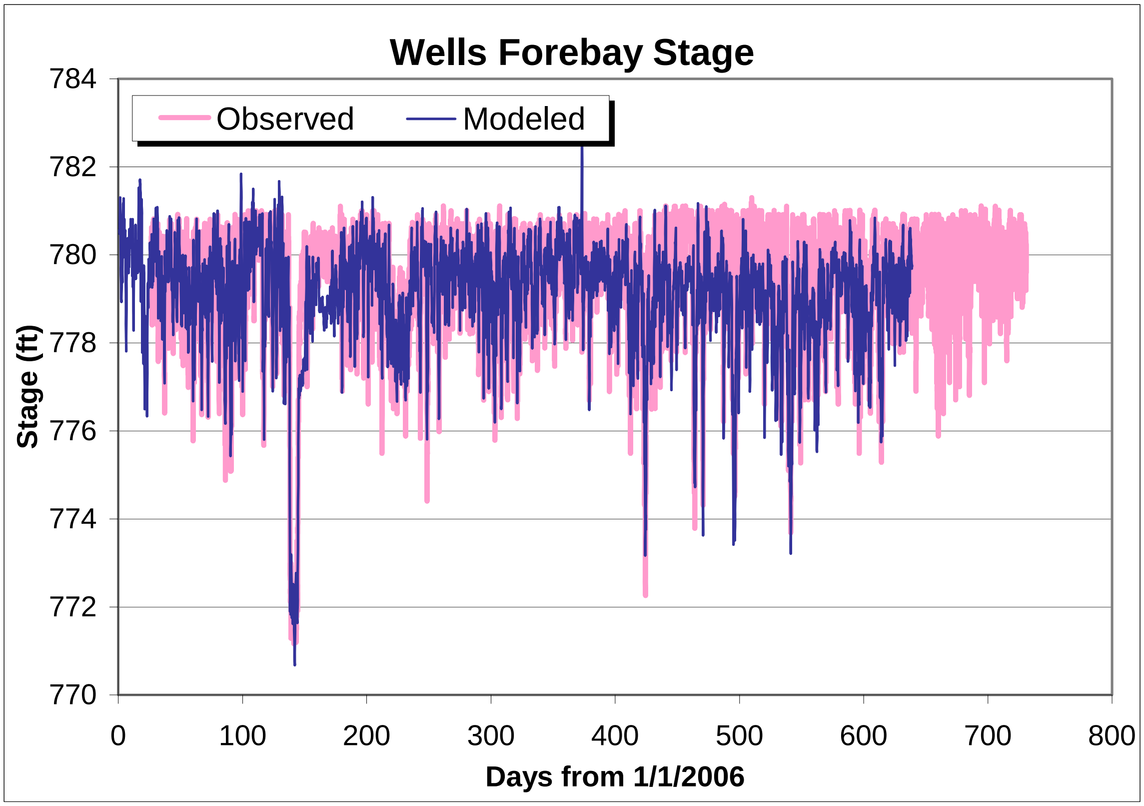

Figure 5.1-8 Wells forebay simulated and observed stage after water balancing.

5.1.2.1 Water Temperature Inflows

Water temperature data were input into the model for three inflow locations into the Wells Reservoir; Chief Joseph Dam outflow, the Okanogan River, and the Methow River. Douglas PUD provided hourly temperature data from the Chief Joseph Dam tailrace (Figure 5.1-9). Hourly temperature data for the Okanogan River near Malott (USGS Gauge No. 12447200) were obtained from the USGS for January 1, 2006 through September 30, 2007 (the end of Water Year 2007) (Figure 5.1-10). Douglas PUD measured hourly temperatures at the upstream and downstream ends of the Project reach on the Methow and Okanogan Rivers, and provided these data. There are no USGS temperature gauges on this reach of the Methow River.

The upstream gauge on the Methow River had large data gaps because it was difficult to retrieve the instrument when the river iced over, and significant amounts of data were lost. However, a comparison of data between the upper (above project boundary) and lower (Methow RM 0.0) gauges showed that the measurements were very similar (the reach is only 1.5 miles long), and data from the lower gauge were used to fill the data gaps retrieved from the upper gauge. The resulting inflow temperatures for the Methow River are shown in Figure 5.1-11. Raw data from Chief Joseph and the Okanogan River had very few missing values. The temperatures are shown in “degrees-C” in these figures. Inflow temperature data for the Methow River were also used to describe the temperatures of the “added” distributed sources.

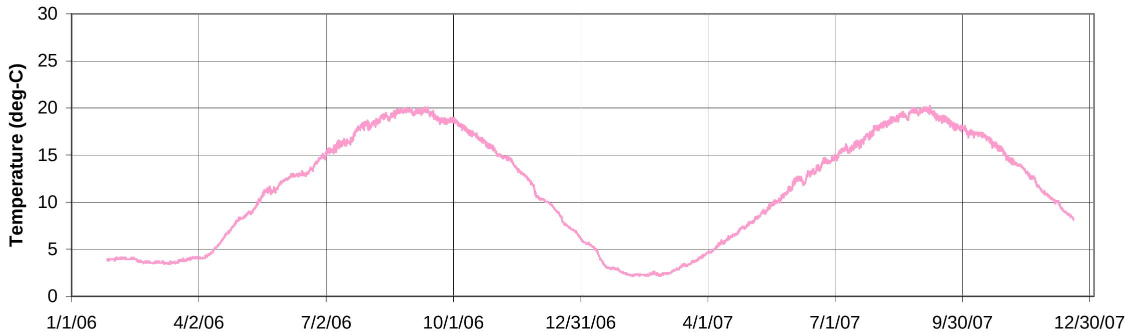

Figure 5.1-9 **Hourly temperatures in the Chief Joseph Dam tailrace.**

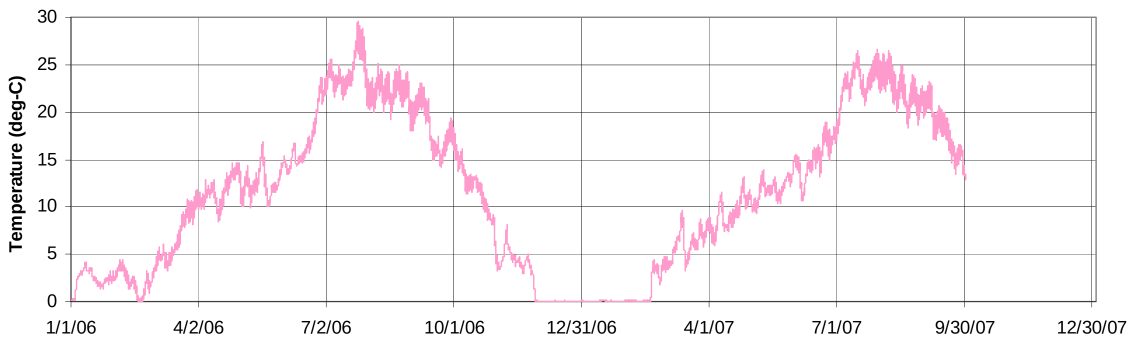

Figure 5.1-10 **Hourly temperatures from USGS gauge on Okanogan River at Malott (at RM 17, approximately 1.5 miles upstream of the Wells Project boundary).**

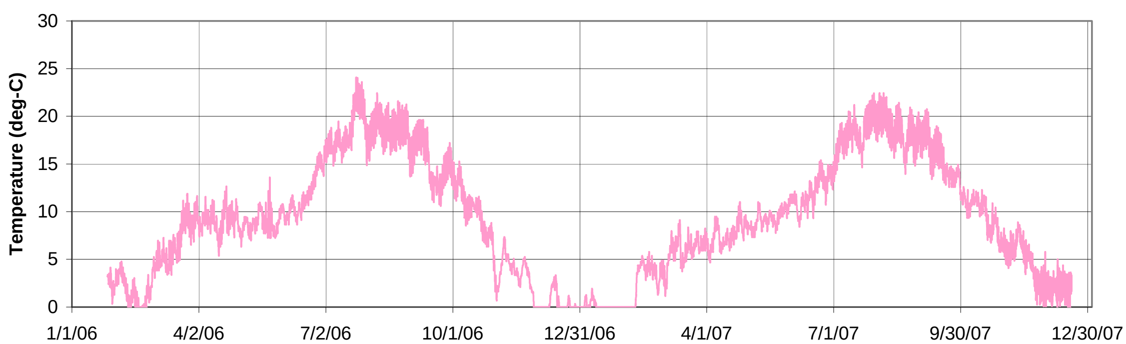

Figure 5.1-11 **Hourly temperatures on Methow River near Pateros (RM 1.5).**

5.1.3 Meteorology

Meteorological data are available at three stations in the vicinity of the Wells Reservoir (Figure 5.1-2). The U.S. Bureau of Reclamation maintains a station just upstream of the Chief Joseph Dam. Douglas PUD maintains a station at Bridgeport Bar, and another on Wells Dam, and collected wind speed and direction in the forebay about three miles upstream of the dam. In addition, there is a NOAA National Weather Service (NWS) station at Omak airport.

5.1.3.1 Air Temperature

Figure 5.1-12 shows the air temperature (in degrees-C) at the Wells, Bridgeport Bar and Chief Joseph meteorological stations. The data show little variability between the stations.

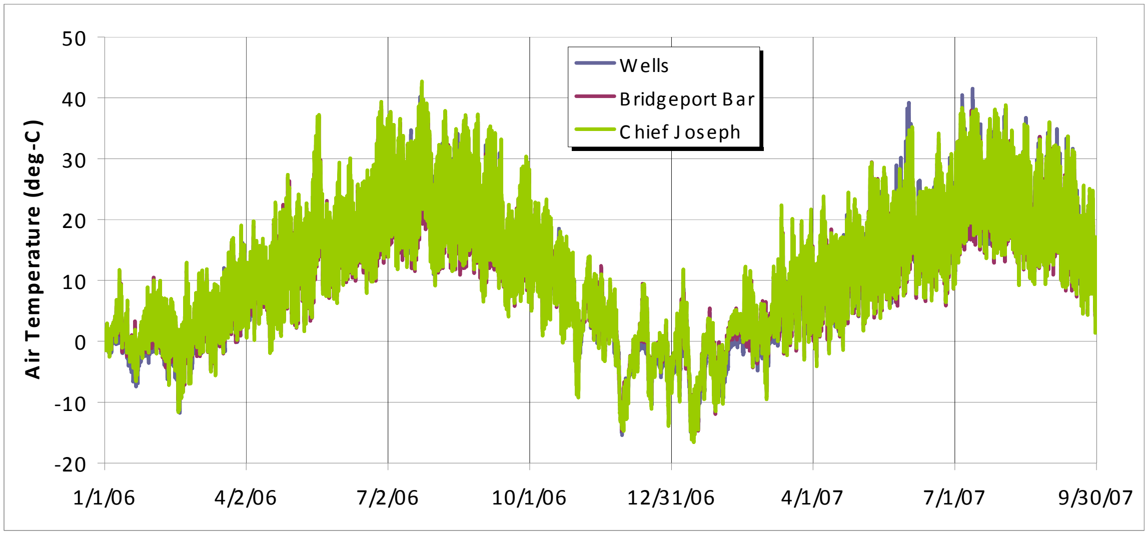

Figure 5.1-12 Air temperatures at meteorological stations.

5.1.3.2 Dew Point Temperature Data

Figure 5.1-13 shows the dew point temperature (in degrees-C) at the Wells, Bridgeport Bar and Chief Joseph meteorological stations. The data show little significant variability between the stations, except at the Wells station. The Wells data have a number of suspect values and were not considered further.

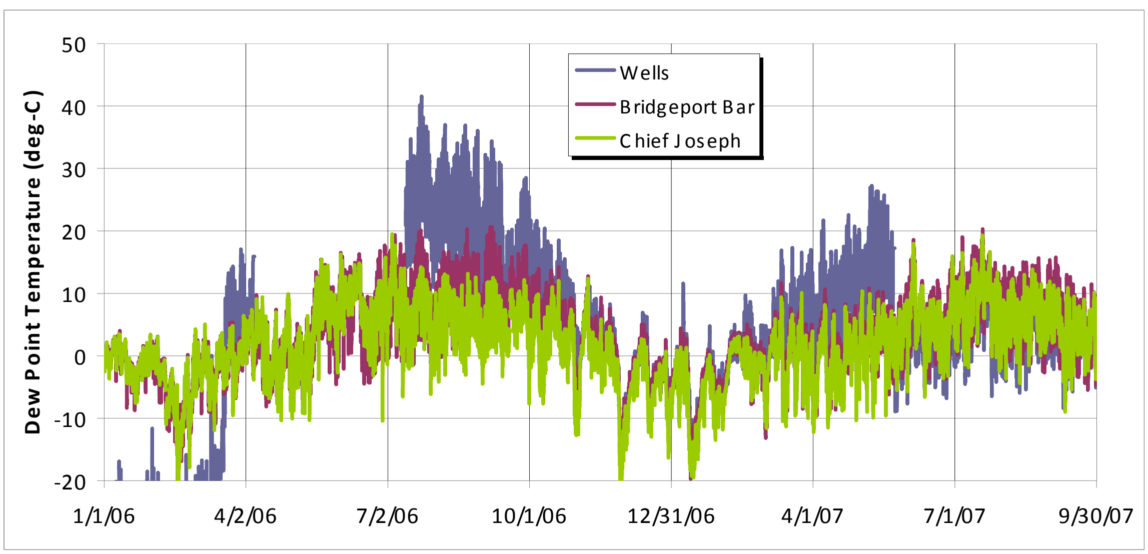

Figure 5.1-13 Dew point temperatures at meteorological stations.

5.1.3.3 Wind Speed and Direction, and Sheltering

There were three meteorological stations in the vicinity of the Wells Project that measured wind speed and direction: “Wells Forebay” (about three miles upstream of the dam), Bridgeport Bar, and near Chief Joseph Dam (Figure 5.1-2). Wind speed and direction are also measured at Omak Airport. Figure 5.1-14 shows the variation in wind speed. Analyzing wind speeds at the three gauges shows that, on average, the wind speeds measured at Chief Joseph are about 59 percent of those measured at Bridgeport Bar, and the wind speeds measured at the “Wells Forebay” are about 104 percent of those measured at Bridgeport Bar. These data reflect the similar valley conditions at Wells and Bridgeport Bar, compared to the topographic sheltering seen near Chief Joseph.

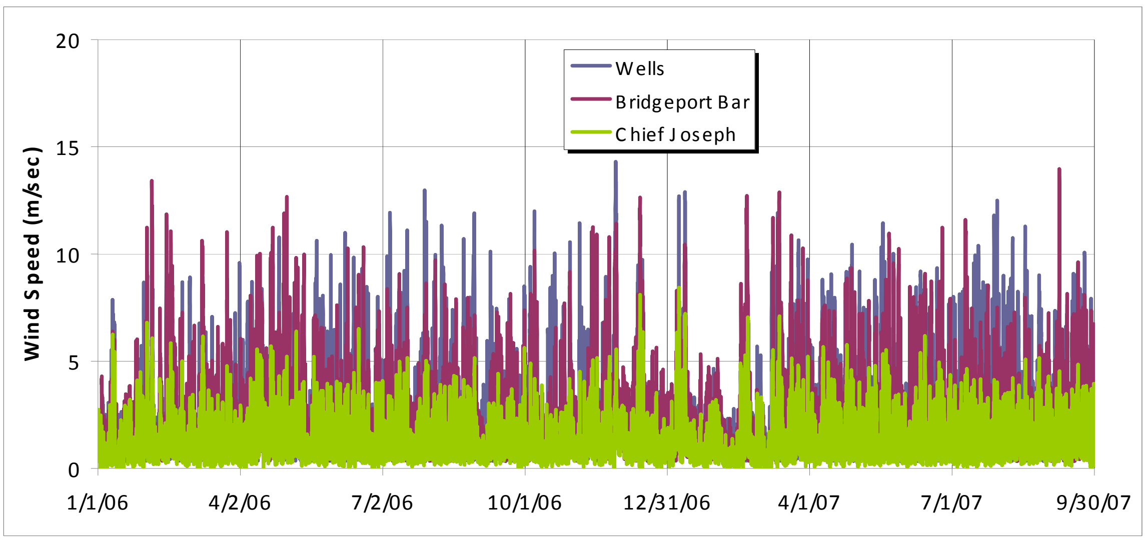

Figure 5.1-14 Wind speeds at meteorological stations.

Wind direction is more difficult to analyze because wind can blow from nearly every direction during a short period of time (e.g., one week), and there are clear differences between the stations. One way to view wind direction data is to plot wind speeds and directions in an excursion plot, and note the net direction of the long-term wind movement. Data from the three stations and Omak Airport are plotted for January 2006 in Figure 5.1-15. During this period, the winds are predominantly from the south (as seen at Omak Airport), but the responses at the three “project” stations differ. The winds at the “Wells Forebay” station appear to blow across the reservoir, while those at Bridgeport Bar and Chief Joseph seem more aligned with the reservoir axis. A closer review of the data indicates that there are periods when the wind appears to be “steered” by the terrain, and other times when it is not. This makes it difficult to decide the best way to use these data in the model. There are several possibilities. First, a single station could be selected (probably Bridgeport Bar) and wind speeds adjusted using the “wind sheltering” parameter in W2 to modify wind speed elsewhere. Second, the system could be broken into three “water bodies”, and a different meteorological station applied to each. Third, the W2 code could be modified to use only one meteorological station (probably Bridgeport Bar) but force the wind direction to align with the local segment direction. Each of these alternatives has its “pros” and "cons". While we prefer the first approach, to use only the data from Bridgeport Bar and adjust for "wind sheltering", because of its simplicity, we decided to first conduct a sensitivity analysis to examine the effect of including the wind before making a final determination.

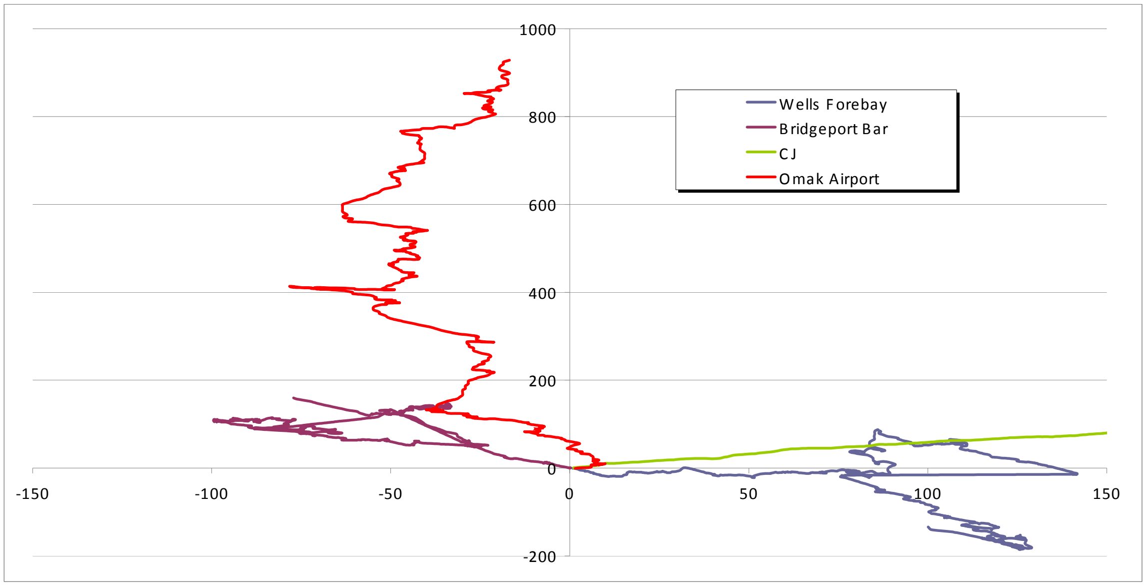

Figure 5.1-15 Wind excursion at meteorological stations during January 2006.

5.1.3.4 Cloud Cover Data

None of the meteorological stations along the reservoir measure cloud cover. However, there is a NWS station at Omak Airport that includes cloud cover (Figure 5.1-16). These data were used in the model.

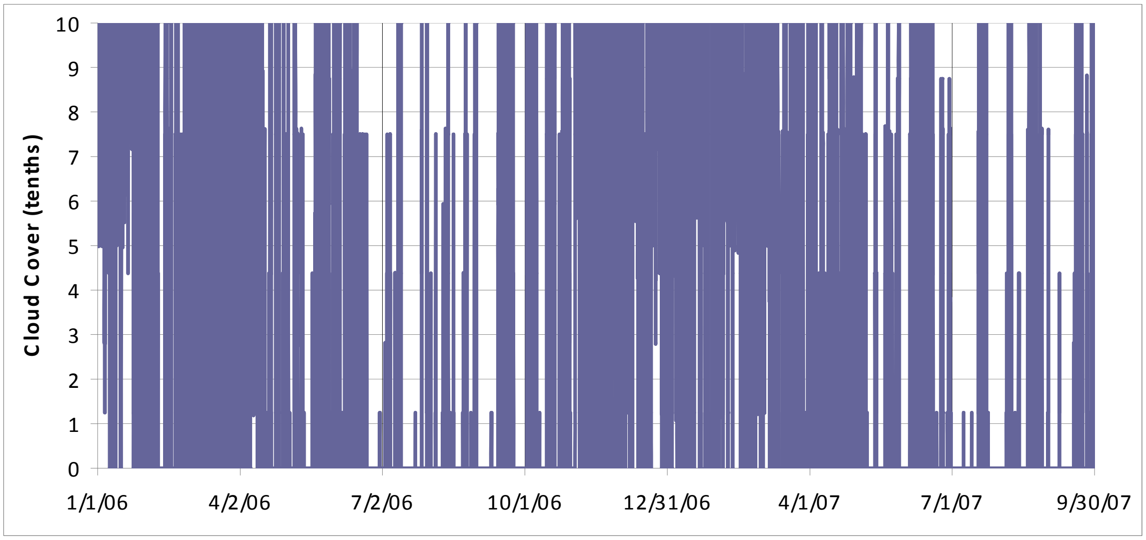

Figure 5.1-16 Cloud cover at Omak Airport.

5.1.3.5 Solar Radiation Data and Dynamic Shading

Figure 5.1-17 shows solar radiation (in Watts/m^2) at the Wells, Bridgeport Bar and Chief Joseph meteorological stations. The data show little significant variability between the stations. Figure 5.1-18 shows an arbitrary 10-day period to illustrate the similar values between stations.

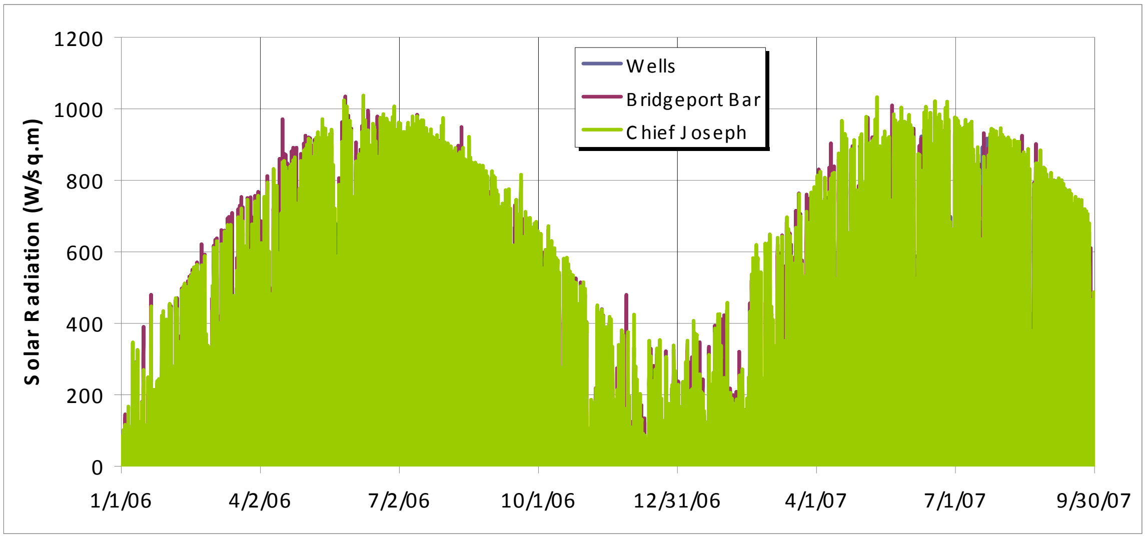

Figure 5.1-17 Solar radiation at meteorological stations.

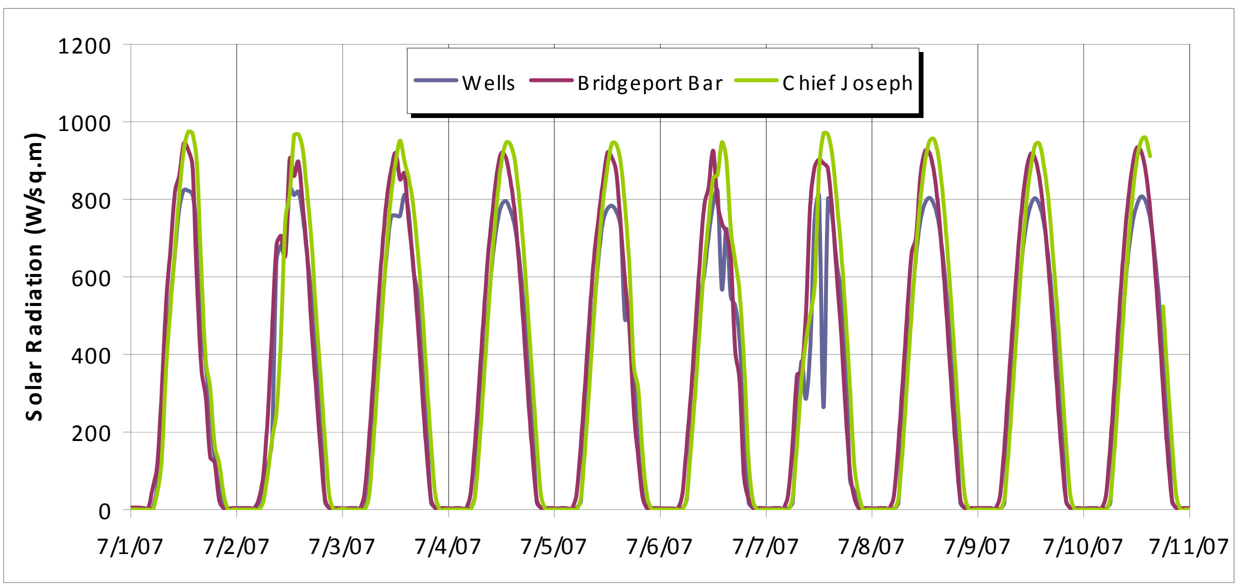

Figure 5.1-18 Solar radiation for an arbitrary 10-day period.

At low sun angles (early morning and late afternoon) it is possible that the sun may not shine directly on the water surface, especially if the river is deeply incised and/or is shaded by mountains. In W2, this effect can be introduced using the "dynamic shading" option. Starting from north (zero degrees), the limiting azimuth angle that the sun can strike the water surface is defined. W2 then uses the Julian day (from January 1), and the latitude and longitude of the project location to calculate the sun angle and azimuth, and compares it against the minimum azimuth for that direction. If the sun is below the horizon, the solar radiation is reduced to zero for that time step. Using the (x,y,z) coordinates of the centers of each model segment, we used a USGS 30 m Digital Elevation Model, freely available on the Internet, to compute the limiting azimuth angles. Dynamic solar shading data sets were created for the with-Project conditions using a normal reservoir elevation of 238 m (780.8 feet msl), and for without-Project conditions using water surface elevations determined from an HEC-RAS model of the system (GeoEngineers, 2008). Compared to the normal reservoir elevation of about 238 m (780.8 feet msl), typical flows in the system without the Project would results in water surface elevations of about 225.5 m (740 feet msl) at the confluence with the Okanogan River, about 221.5 m (727 feet msl) at the confluence with the Methow River, and about 214 m (702 feet msl) at the Wells Dam location. The water surface elevation at the dam would be approximately 24 m (80 feet) lower if the dam were not present.

5.1.4 Observed In-Reservoir Temperatures

Continuous water temperature was measured at the five interior locations in the Wells Reservoir during 2006 and 2007 (Figure 5.1-2). Several locations recorded temperature at multiple depths in the water column. The temperature gauges were anchored to the bed, and maintained at a fixed elevation above the bed. Table 5.1-1 summarizes the gauge locations and elevations.

Table 5.1-1 Summary of Water Temperature Recording Gauges.

Location	Date and time deployed	Depth below water surface (ft)	Forebay elevation at deployment (ft NGVD)	Estimated elevation of gauge (ft NGVD)
Erlandsen’s (mid)	1/26/06 12:00	30	780.4	750
Erlandsen’s (bottom)	1/26/06 12:00	50	780.4	730
Lower Okanogan R. (bottom)	1/26/06 14:00	32	780.2	748
Brewster Bridge (mid)	1/26/06 15:00	*25*	780.1	755
Brewster Bridge (bottom)	1/26/06 15:00	46	780.1	734
Lower Methow River (mid)	1/26/06 12:00	19	780.4	761
Wells Forebay (surface)	1/26/06 16:00	“surface”	780	<780
Wells Forebay (mid)	1/26/06 16:00	30	780	750
Wells Forebay (bottom)	1/26/06 16:00	50	780	730

5.2 Model Development and Calibration

5.2.1 Modeling Approach

We used the following approach in modeling the Project:

- Develop the geometry for the reservoir;

- Ensure that the model flows would "balance" water in the reservoir;
- Perform model sensitivity to determine the optimum set of model parameters;
- Calibrate the "with Project" model to observed, in-reservoir continuous temperature measurements ("time series") collected during 2006 and 2007;
- Modify the input files to develop a "without Project" model; and
- Run the "without Project" model for the same period, and compare the resulting temperatures.

The PUD collected large amounts of temperature data during 2006 and 2007. USGS flow data and temperatures were available through September 2007. Therefore, we decided to calibrate the W2 model of the Wells Project for the period 1/1/2006 to 9/30/2007. This period contains two high-temperature summer periods, which is the main period of interest for this study.

5.2.2 Description of the Numerical Model

W2 is a two-dimensional, laterally-averaged hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients. The model has been applied successfully to numerous rivers, lakes, reservoirs and estuaries.

The hydrodynamic routine of the model predicts water surface elevations, velocities and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density. The water quality routines simulate any combination of constituents that can represent a range of simple-to-complex eutrophication kinetics and various trophic levels. The model includes algal dynamics driven by nitrogen, phosphorus and silicon, and carbon cycling. Both water column and interactions with sediment can be modeled as defined by the user. W2 uses an internally-calculated time step, to maximize computational efficiency and minimize model instability problems. The user can specify a minimum and maximum time step. For this study, we used W2 Version 3.5 (Cole and Wells 2007).

5.2.3 Development of the "Existing Conditions" Model

Detailed bathymetry data of the Wells reach, including Wells Reservoir, the lower 1.5 miles of the Methow River, and the lower 15.5 miles of the Okanogan River, were provided to the project team. Figure 5.2-1 shows the resulting reach bathymetry.

GeoEngineers, Inc. developed a geo-referenced HEC-RAS 1-D hydraulic model of the Wells Reach to develop backwater curves at various flows (GeoEngineers 2008). The geometry data for this W2 model were developed from the detailed bathymetric survey of the reservoir. We then processed the model geometry to develop stage-width curves at 0.5-m intervals at each cross section, and then averaged the data between cross sections to develop stage-width relationships corresponding to W2 "segments." Some smaller segments were merged, and some additional sections were cut through the GIS coverage, to create more resolution in some areas and to refine the detail in the Columbia River near the confluence with the Okanogan River.

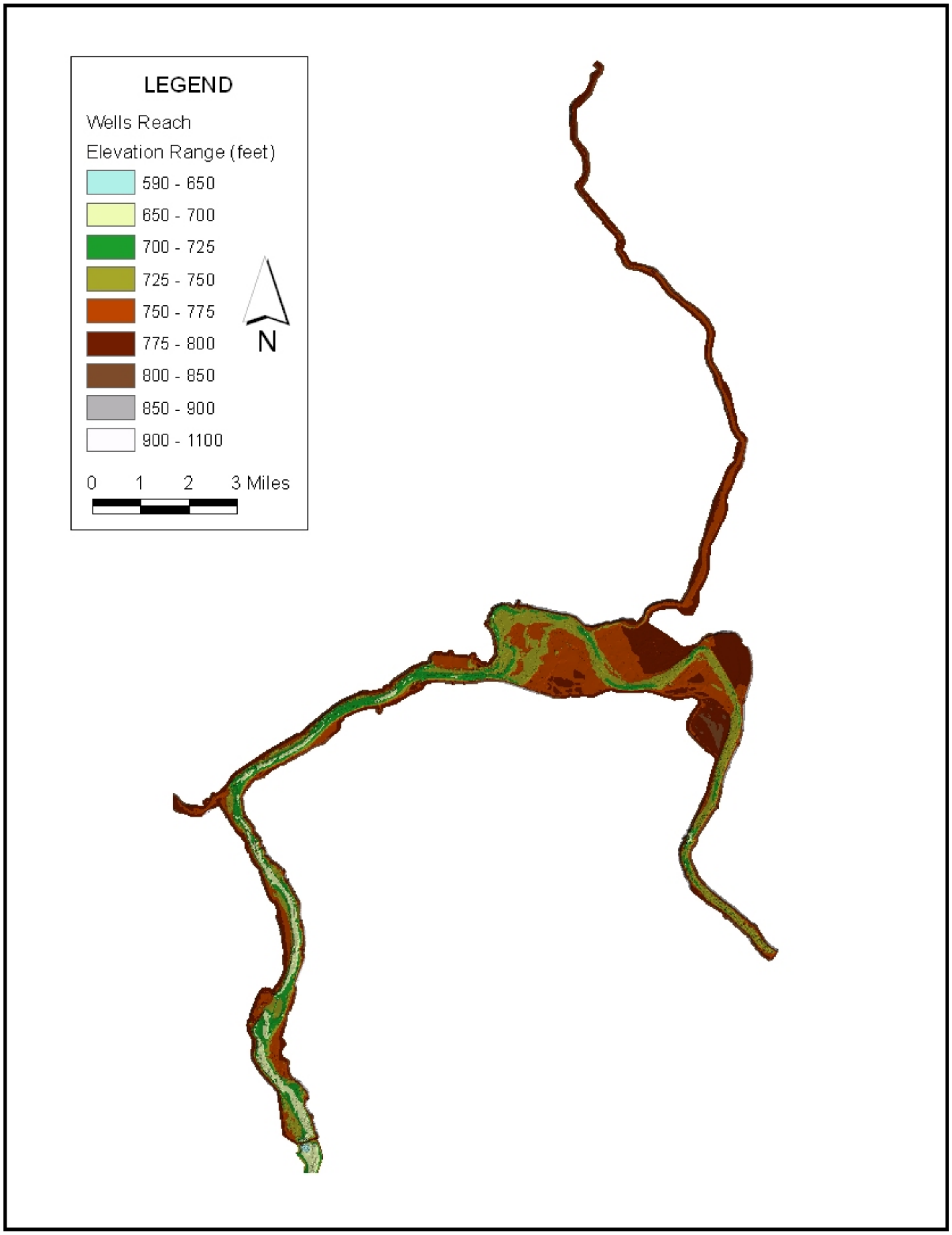

Figure 5.2-1 Wells Reach Bathymetric Data.

Figure 5.2-2 compares the resulting model geometry (stage-area and stage-volume) with data from the detailed bathymetric survey, and demonstrates that the model is a good representation of the physical geometry. The average horizontal resolution is approximately 470 m (1,550 ft). In the initial model, there were 90 segments along the Columbia River, 53 segments along the lower Okanogan River, and 8 segments along the lower Methow River. The geo-referenced HEC-RAS model was also used to develop segment lengths and orientations, and to specify Manning coefficient of roughness values.

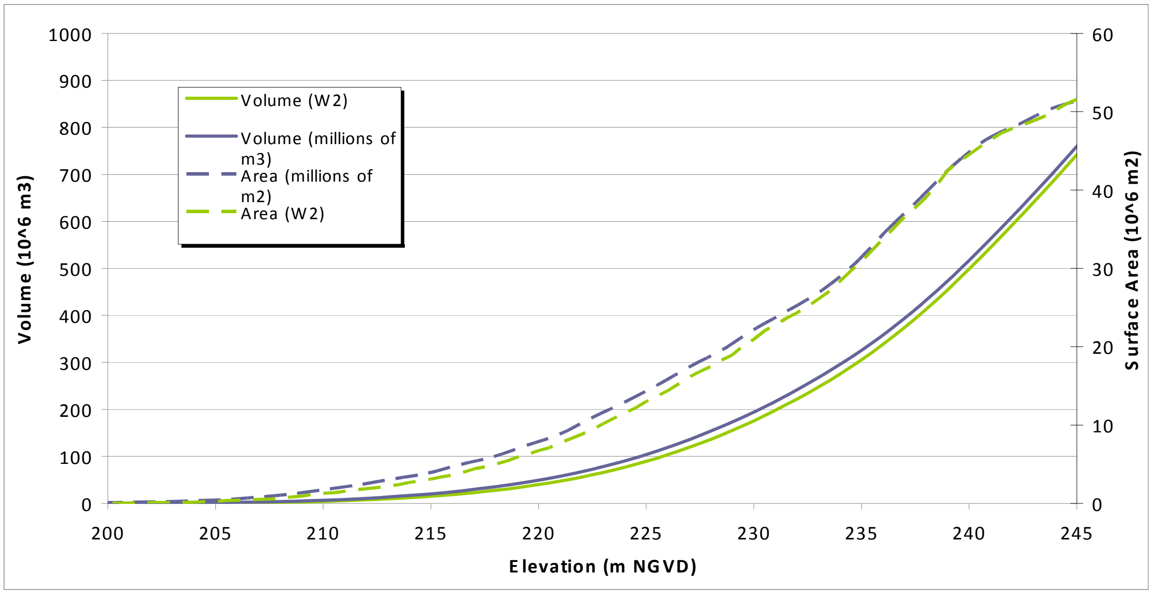

Figure 5.2-2 Comparison of model and survey geometries.

Wells Dam releases water through the turbine generators, through the spillway, and from the surface to fish ladders on either side of the dam. Table 5.2-1 summarizes these data, which were used to specify the elevations and widths for downstream flows in the W2 model "control" file.

Table 5.2-1 Reservoir and Dam technical specifications.

Feature	Wells Reservoir and Dam	
	Elev (ft) (NGVD)	**Elev (m) (NGVD)**
Low point in reservoir (for 0.5 m vertical resolution)	640	195
Normal Reservoir operating range	771-781	235-238
Normal maximum operating level	781	238
Spillway crest elevation	716	218.2
Spillway gates	11 46x65 gates	11 14x19.8
Intake elevation to generators	646-706	197-215.2
Intake width	10 25-ft	10 7.6-m
Fish ladder withdrawals	Surface	Surface

5.2.4 Initial and Boundary Conditions Data

The reservoir model requires initial and boundary conditions. These are:

- Initial reservoir stage;
- Initial reservoir temperatures;
- Inflows to the reservoir;
- Water temperatures of the reservoir inflows;
- Outflows from the reservoir through the various structures; and
- Meteorology.

The W2 model was run for the period 1/1/2006 to 9/30/2007, with a maximum time step of one hour. As the reservoir stage on 1/1/2006 was very close to its normal maximum operating level of 781 ft (238 m), the initial stages in the reservoir were set to 238 m (780.9 feet msl). The reservoir temperatures are cold at the beginning of each year. The initial reservoir temperature was set to a uniform value of 1^{o}C. Temperatures this low have been measured in the Okanogan and Methow rivers, and initial simulation showed that the model adjusts from this initial condition by the time the first in-reservoir temperatures are measured on 1/26/2006. Observed reservoir inflows and outflow, and inflow temperatures were specified from observations (see Figure 5.1-1). Meteorological data from the Brewster station were used in the model, with cloud cover data from Omak Airport.

5.2.5 Initial Model Runs

The initial model included the Columbia River from Wells Dam to Chief Joseph Dam, the lower 15.5 miles of the Okanogan River, and the lower 1.5 miles of the Methow River. When this initial model was run, however, it became numerically unstable in the upper reach of the Okanogan River at the upstream limit of the relatively flat backwater from the confluence. This upstream limit is influenced by the flow in the Okanogan River.

For much of the simulation, the model runs without numerical instabilities. However, instabilities were seen in mid- to late-May 2006 when two things happened: the reservoir was lowered from about 238 m (780.9 feet msl) to about 235.25.m (771.8 feet msl), and at the same time a significant flood occurred on the Methow and Okanogan rivers. As W2 generally uses horizontal layers to model reservoirs, and the surface elevation is constrained to be in the same vertical layer throughout a "waterbody", when the reservoir is lowered to 235.25 m (771.8 feet msl) the most upstream segments in the Okanogan River have top-layer thicknesses approaching 10 m, with underlying layers of only 0.5 m thick. This is a very unstable combination numerically, and the model fails.

Figure 5.2-3 shows three example profiles on the lower 15.5 miles of the Okanogan River developed from the HEC-RAS one-dimensional hydraulic model. The lowest profile ("PF1") specifies the stage in the reservoir forebay at 238 m (780.8 feet msl) and includes moderate reservoir inflows. The second profile ("PF2") again holds the reservoir stage at 238 m (780.9 feet msl), but includes flood flows on the three rivers. The third profile ("PF3") lowers the forebay reservoir stage to 235.25 m (771.8 feet msl), and includes the flood flows of late May 2006. The results show that the lower 6-7 miles of the Okanogan River are relatively unaffected, but that the water surface elevations rise sharply farther upstream in response to flood flows on the Okanogan River. In addition, Figure 5.2-4 compares the observed hourly temperatures at the USGS gauge at Malott (RM 17) with hourly observations at the PUD gauge at Wakefield Bridge (RM 10.5), for August and September 2006. The temperatures are generally similar, with those at the Wakefield Bridge gauge showing some “damping” (lowering of daily maximum temperatures and raising of daily minimum temperatures) due to the backwater effect from the Wells Project.

To overcome this numerical instability, a shorter reach of the Okanogan River was modeled to capture only the extent of the backwater at high flows in the Okanogan River combined with the simultaneous lowering of the Wells Reservoir, and to test the effect of this through sensitivity analyses. Therefore, three additional models were created: (1) a model of the Columbia River only (only the Okanogan and Methow River inflows and temperatures were added); (2) a “short Okanogan River” that included the lower 6 miles; and (3) a “longer Okanogan River” that included the lower 11.3 miles, which is the most upstream reach influenced by backwater effects from the Columbia River under Project conditions. In addition, a sensitivity analysis was performed to compare the use of temperatures from the Malott gauge with the use of temperatures from the Wakefield Bridge on results in the lower Okanogan River and in the Columbia River.

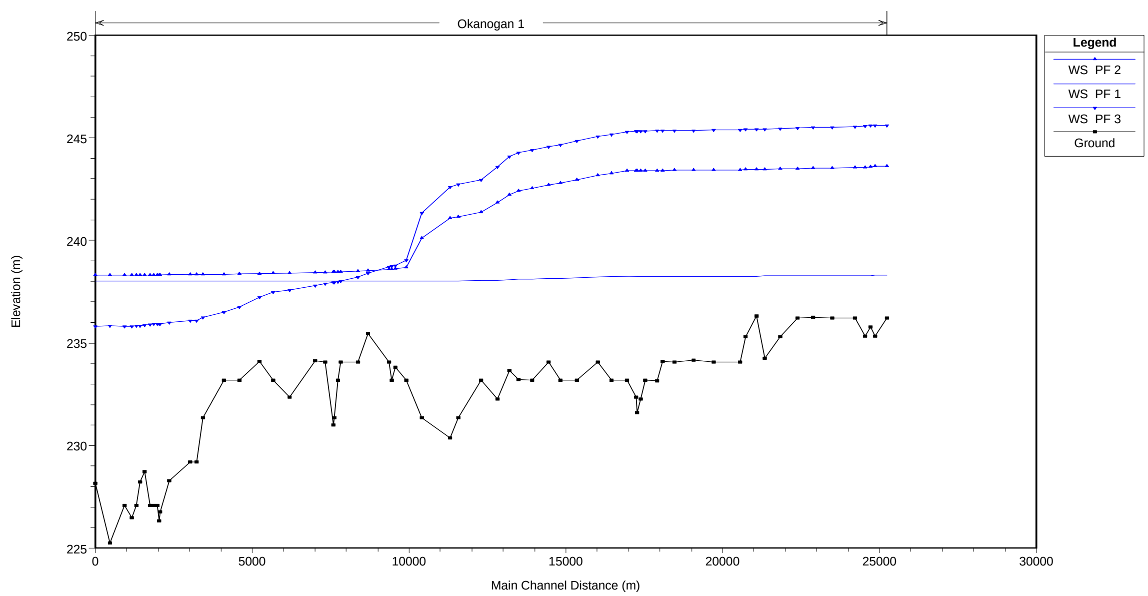

Figure 5.2-3 Flow profiles on lower Okanogan River.

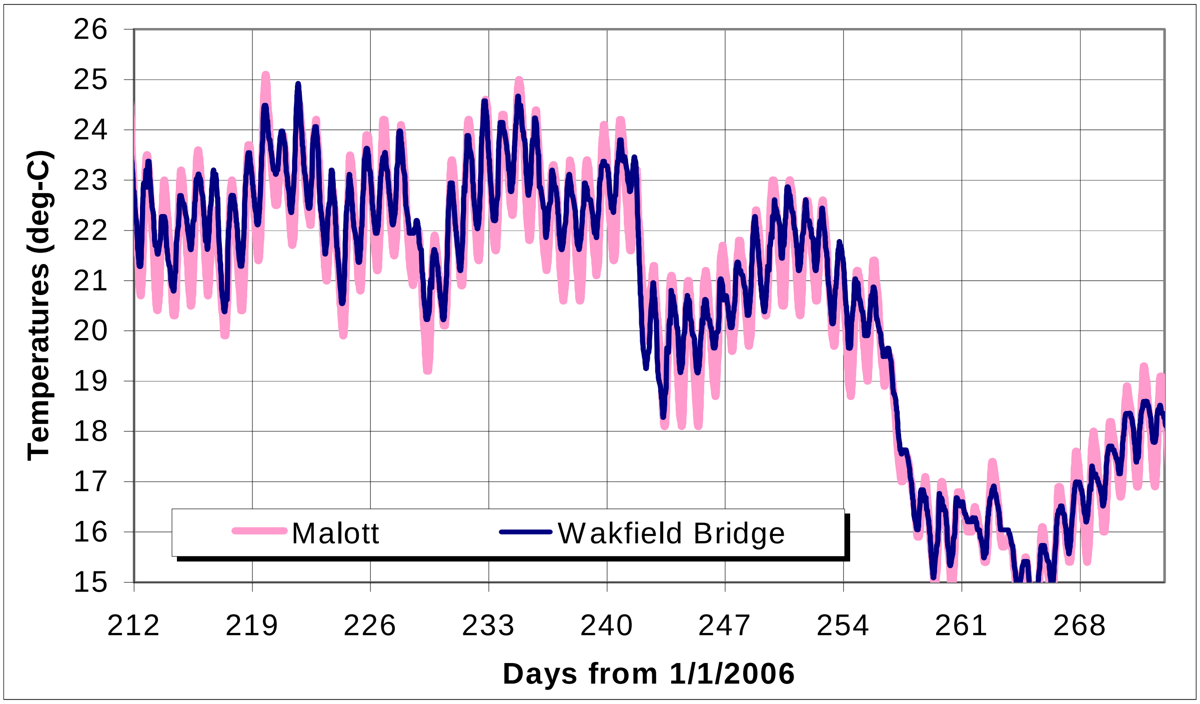

Figure 5.2-4 Comparison of observed temperatures at Malott (RM 17) and Wakefield Bridge (RM 10.5) on Okanogan River.

5.2.6 Hydrodynamic Calibration

The hydrodynamic (stage) calibration of the reservoir was achieved by using "additional" inflows, developed from a mass balance of observed inflows and outflows, to force a good agreement with observed reservoir stages (Figures 5.2-2 and 5.1-8).

5.2.7 Model Sensitivity and Calibration

The W2 model has relatively few calibration parameters. They include the grid resolution, Manning coefficient of roughness values, the choice of turbulent mixing scheme, the choice method used to model surface heat exchange processes, wind sheltering, and solar radiation shading. Other parameters were kept at the default values recommended by Cole and Wells (2007).

The model sensitivity analyses focused on:

1. The length of the Okanogan River included in the model ("Columbia River Only"; "short Okanogan River" of the lower 6 miles; and "longer Okanogan River" of the lower 11.3 miles).
2. The inclusion of wind mixing and thermal exchange ("no wind" and "no solar").
3. The method to compute the rate of thermal exchange with the atmosphere ("ET" is an equilibrium temperature approach, and "TERM" includes all the solar exchange terms).

4. The method to compute vertical turbulent mixing (“W2N”, “PARAB”, “NICK”, “RNG”, and “TKE” – these methods are fully described in Cole and Wells [2007]).
5. The effect of increasing the Manning coefficient of roughness values (base values; and 110% of base values).
6. The use of temperature data from the USGS gauge at Malott or the PUD gauge at Wakefield bridges as Okanogan River inflow temperatures.

The “base case” was taken to be the “longer Okanogan River” (the lower 11.3 miles), using the equilibrium temperature method (“ET”) to simulate thermal exchange, including the wind and solar radiation processes, and using the “W2N” method the compute vertical turbulent mixing. Several of the simulations became unstable under these conditions, with only one “parameter” changed (to test its sensitivity). In these cases, the “short Okanogan River” geometry was used. These instances are noted with a “*” in the following summary tables.

Following each simulation, a range of summary statistics was developed that compared the model results with observations at the monitoring stations (Figure 5.1-2). The statistics included mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and the correlation coefficient (COR). Of these statistics, the mean errors were generally close to zero, and the correlation coefficients were generally very close to “1”, so little is illustrated by reporting their values. Instead, the mean absolute error (MAE; Table 5.2-2) and the root mean square errors (RMSE; Table 5.2-3) for the various sensitivity simulations were reported.

Based on these results, as shown in Tables 5.2-2 and 5.2-3, the following conclusions were drawn:

- The inclusion of the Okanogan River, or of the Methow River, has little effect on temperatures in the Wells Forebay.
- The use of the “W2N” method to compute turbulent mixing produces the best results.
- There is little difference between the equilibrium temperature (ET) and the term-by-term (TERM) methods for computing surface heat exchange. Cole and Wells (2006) note that while the term-by-term method has a stronger theoretical foundation, the equilibrium temperature method often gives better results with less computational effort.
- Including the wind terms has only a small effect. This is not surprising given the relatively short residence time (about one day at high flows, to 10-12 days at low flows) in Wells Reservoir.
- Inclusion of the surface heat exchange processes is perhaps the most significant process affecting model calibration.
- Modest variations in roughness (Manning coefficient of roughness) cause little difference in reservoir temperatures.
- The use of temperature data from the PUD gauge at Wakefield Bridge improved the results in the lower Okanogan River with no effect on the results in the Columbia River.

Figure 5.2-5 through Figure 5.2-7 illustrate some of the differences seen in the model sensitivity analyses. Figure 5.2-5 looks at the effect of including the lower Okanogan River in the model simulation. While the results show only small differences downstream of Brewster Bridge, some differences can be seen in the reservoir near the confluence of the Columbia River and the Okanogan River. We believe that the inclusion of at least some of the lower Okanogan River allows vertical mixing in the vicinity of the rise in the bed elevation of the Okanogan River located 3-6 miles upstream of the confluence (Figure 5.2-3). There does appear to be little difference, however, between including either 6 miles or 11.3 miles of the lower Okanogan River.

Table 5.2-2 Mean absolute errors for sensitivity analyses.

		Temperature (°C)								
Condition	**Forebay stage (m)**	**Erlandsen's (mid)**	**Erlandsen's (bot)**	**Lower Okanogan**	**Brewster Bridge (mid)**	**Brewster Bridge (bot)**	**Lower Methow River (mid)**	**Wells Forebay (surface)**	**Wells Forebay (mid)**	**Wells Forebay (bot)**
"longer Okanogan River"	0.15	0.24	0.25	0.83	0.16	0.15	0.71	0.16	0.13	0.13
"short Okanogan River"	0.15	0.23	0.24	0.88	0.16	0.15	0.74	0.16	0.12	0.13
Columbia River only	0.14	0.22	0.27		0.16	0.17		0.16	0.12	0.13
Term-by-term solar exchange ("TERM")	0.14	0.25	0.26	0.86	0.17	0.16	0.72	0.18	0.14	0.14
"PARAB" turbulent mixing*	0.09	0.25	0.43	1.30	0.16	0.22	1.02	0.76	0.13	0.19
"NICK" turbulent mixing*	0.09	0.25	0.44	1.28	0.16	0.22	1.04	0.77	0.13	0.19
"RNG" turbulent mixing*	0.09	0.25	0.43	1.30	0.16	0.22	1.02	0.76	0.13	0.19
"TKE" turbulent mixing*	0.09	0.24	0.27	0.77	0.15	0.16	0.70	0.17	0.12	0.13
No wind terms included	0.14	0.24	0.25	0.81	0.17	0.15	0.72	0.17	0.14	0.15
No solar radiation included	0.14	0.23	0.24	0.88	0.19	0.19	0.81	0.28	0.28	0.29
110% of Manning's *n**	0.16	0.23	0.24	0.89	0.16	0.15	0.75	0.16	0.13	0.13
Wakefield Bridge temperatures for Okanogan	0.14	0.12	0.13	0.82	0.16	0.15	0.72	0.16	0.13	0.13

Table 5.2-3 Root mean square errors for sensitivity analyses.

Condition	Forebay stage (m)	Temperature (°C) Erlandsen's (mid)	Erlandsen's (bot)	Lower Okanogan	Brewster Bridge (mid)	Brewster Bridge (bot)	Lower Methow River (mid)	Wells Forebay (surface)	Wells Forebay (mid)	Wells Forebay (bot)
"longer Okanogan River"	0.20	0.38	0.47	1.48	0.20	0.20	1.08	0.20	0.16	0.17
"short Okanogan River"	0.20	0.37	0.46	1.49	0.20	0.20	1.13	0.21	0.16	0.17
Columbia River only	0.19	0.31	0.54		0.21	0.29		0.20	0.16	0.17
Term-by-term solar exchange ("TERM")	0.20	0.39	0.49	1.49	0.22	0.21	1.09	0.23	0.17	0.18
"PARAB" turbulent mixing*	0.12	0.42	0.78	2.00	0.21	0.29	1.46	1.03	0.17	0.24
"NICK" turbulent mixing*	0.12	0.42	0.79	1.99	0.21	0.29	1.47	1.04	0.17	0.24
"RNG" turbulent mixing*	0.12	0.42	0.78	2.01	0.21	0.30	1.45	1.02	0.17	0.24
"TKE" turbulent mixing*	0.12	0.41	0.57	1.24	0.20	0.22	1.07	0.22	0.16	0.17
No wind terms included	0.19	0.38	0.49	1.50	0.21	0.21	1.10	0.22	0.18	0.19
No solar radiation included	0.20	0.35	0.44	1.50	0.25	0.25	1.19	0.34	0.35	0.35
110% of Manning's *n**	0.22	0.36	0.46	1.52	0.20	0.20	1.14	0.20	0.16	0.17
Wakefield Bridge temperatures for Okanogan	0.20	0.17	0.24	1.47	0.20	0.21	1.09	0.20	0.16	0.17

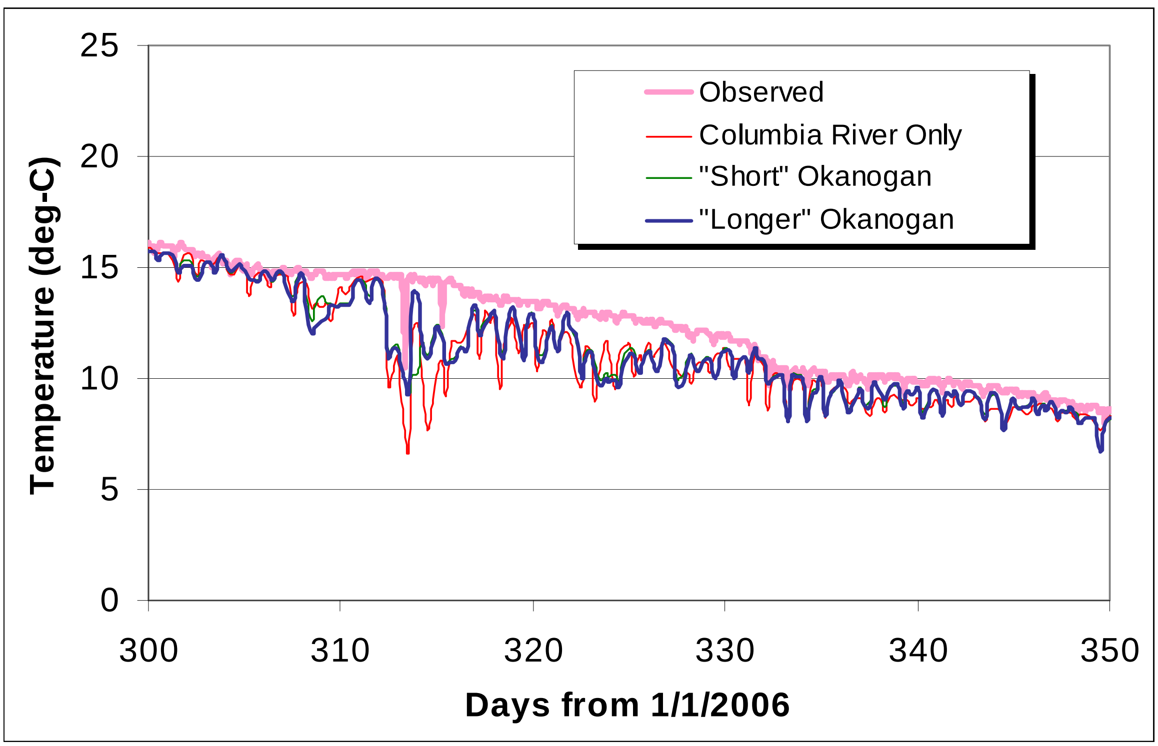

Figure 5.2-5 Effect of including the Okanogan River on the Columbia River at Erlandsen's (bot).

Figure 5.2-6 looks at the effect of including or not including surface heat exchange processes in the model. The effect is more pronounced on the cooling limb of the annual temperature series, as the model cools less quickly when this surface exchange processes are not included. However, the results also show that the diurnal range is relatively small, and that the system is perhaps most influenced by the temperature of the inflows from Chief Joseph.

Figure 5.2-7 looks at the effect of some of the different methods of modeling vertical turbulent mixing in W2. Cole and Wells (2007) recommend using the "W2N" method for relatively deep systems, such as Wells Reservoir, and this seems to be borne out by the model results. The "W2N" method includes more wind-induced mixing than many of the other methods, which are based more on velocity-induced mixing. The results show that the "PARAB" method (the "NICK" and "RNG' methods show similar effects) under-predicts the amount of vertical mixing, and allows the near-surface water to respond more dynamically to surface heat exchange than is seen in the observations. The "W2N" method not only better fits the trend of the observations but also better models the diurnal variations.

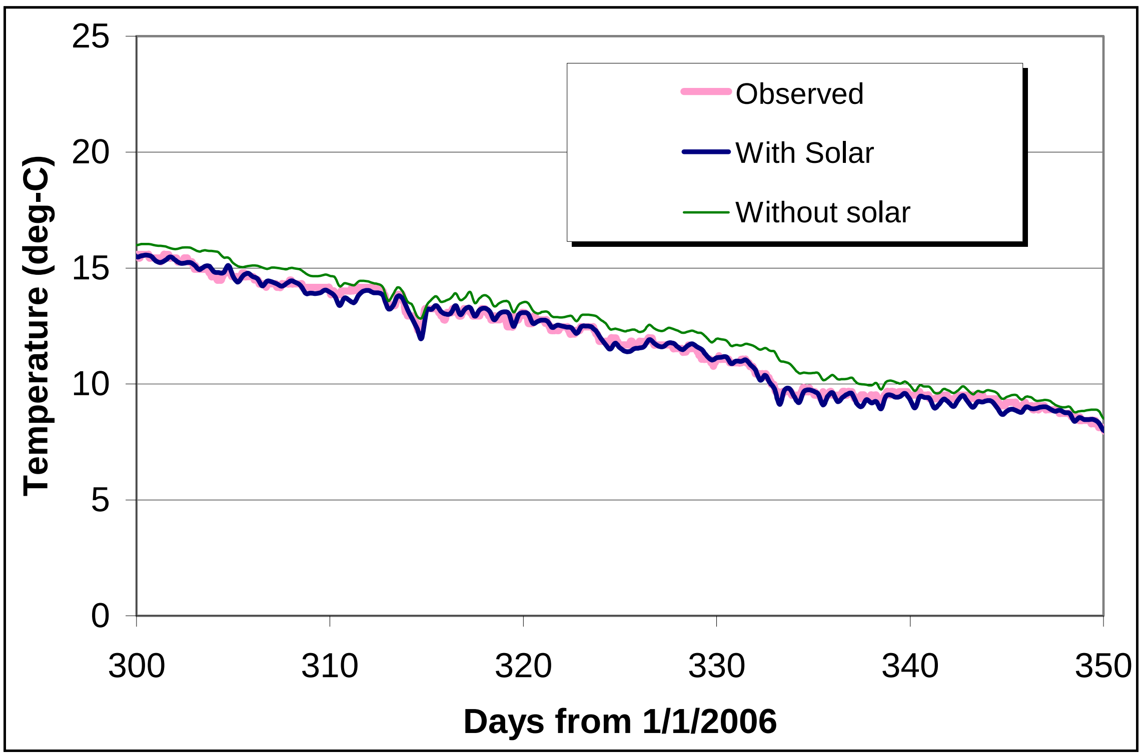

Figure 5.2-6 Effect of including surface heat exchange at Forebay (surface).

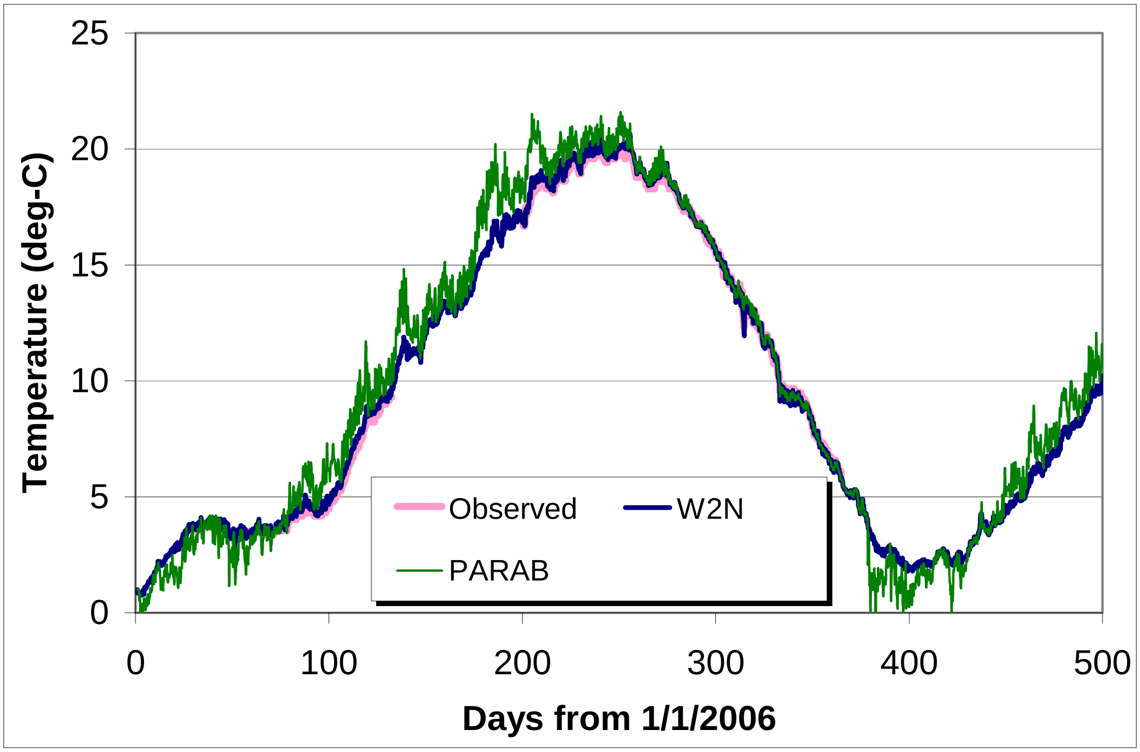

Figure 5.2-7 Effect of vertical mixing methods at Forebay (surface).

5.2.8 Temperature Calibration

From the model sensitivity analyses, it was concluded that temperatures for "existing conditions" are best modeled using the same bottom friction (Manning coefficient of roughness values) as in the HEC-RAS model, that surface heat exchange should be included, that the "W2N" method should be used to model vertical turbulent mixing, and that observations at the Wakefield Bridge gauge should be used to represent Okanogan River inflow temperatures (as this gauge at RM 10.5 is closer to the model upstream boundary at RM 11.3. It appears appropriate to use the wind speed and direction reported at the Bridgeport Bar meteorological station and to use the "wind sheltering" coefficient to modify the wind speed in other areas of the reservoir. The lower 11.3 miles of the Okanogan River was included in the model (1) because this model does run stably and (2) because it provided some temperature mixing in the lower Okanogan River prior to flowing into the Columbia River, which improves the results of the model at the Erlandsen's temperature monitoring site. The results of the "with Project" model calibration are shown in Figure 5.2-8.

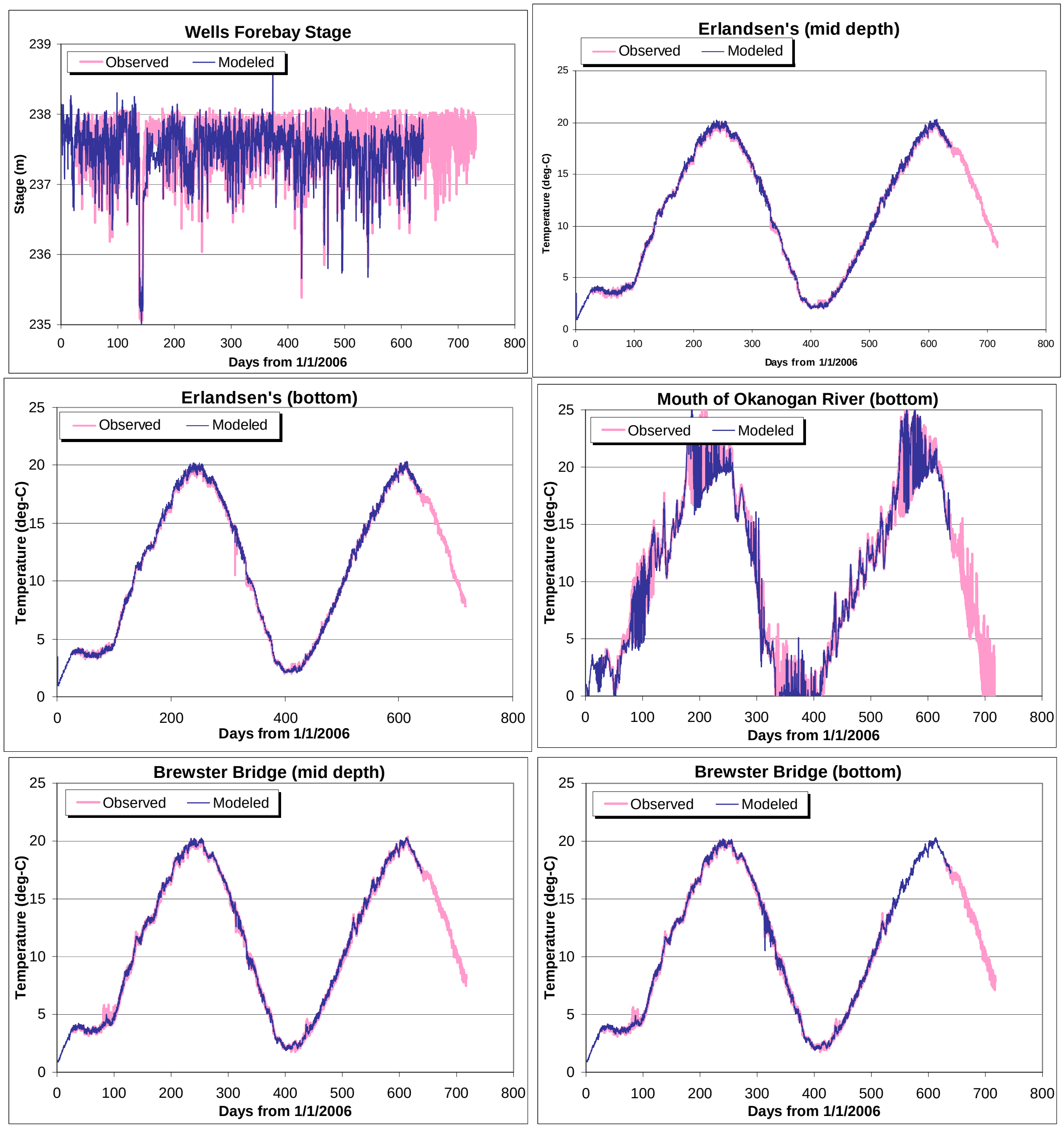

Figure 5.2-8. Calibration of state and temperatures at In-Reservoir stations.

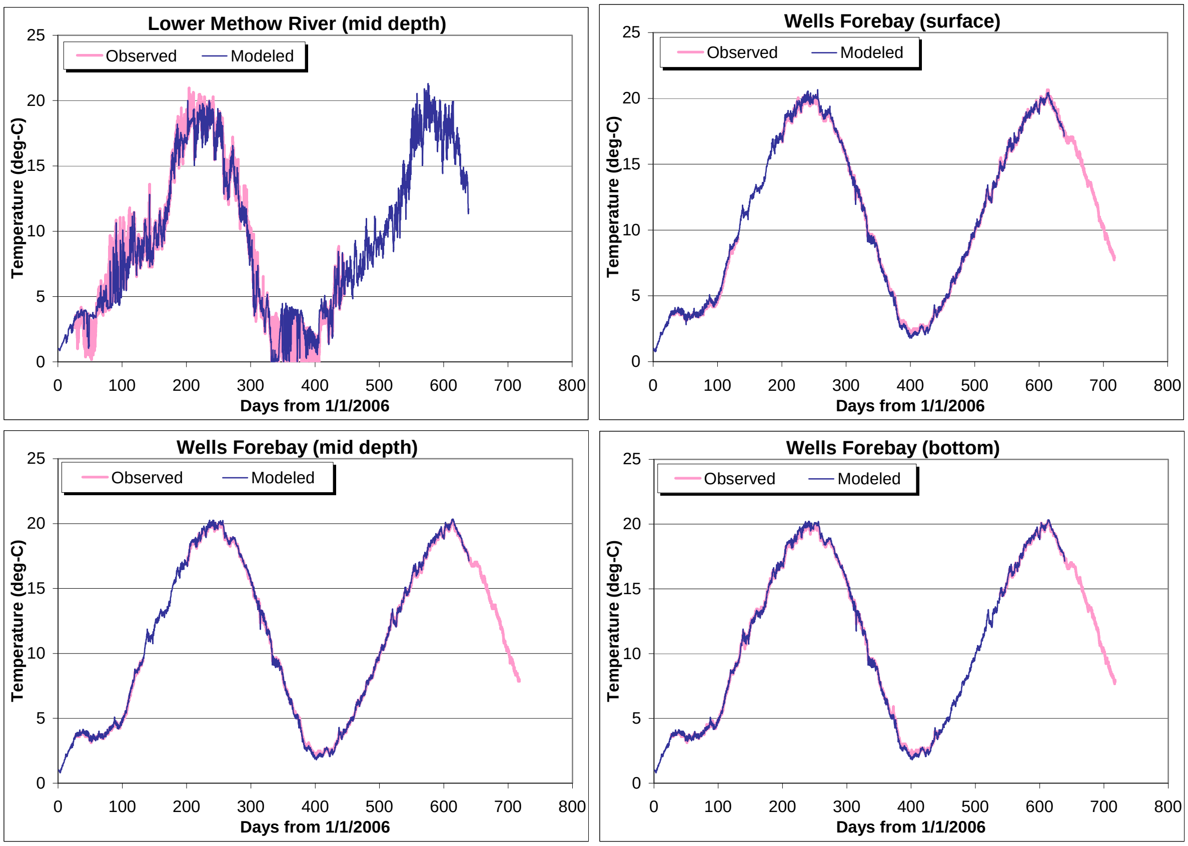

Figure 5.2-8 Calibration of stage and temperatures at In-Reservoir stations.

5.2.9 Development of "Without" Dam Model

The HEC-RAS model developed by GeoEngineers (2008) was used to guide the development of the "without-Project" W2 model. The HEC-RAS model was extended to include about four miles (7,000 m) downstream of Wells Dam, and a starting water surface slope was prescribed at the downstream extent of the model.

Using Figure 5.2-9 as a guide for "normal" and "flood" water surface profiles in the system, the W2 model for "without-Project" conditions:

- divided the Columbia River into two reaches – upstream and downstream of the "weir". In the "without Project" W2 model, a weir was used to hydraulically connect these two reaches;
- did not include a description of the lower Methow River, as the reach is short and very steep. Rather the same flows and temperatures were introduced directly into the Columbia River segment at the confluence with the Methow River;
- included the lower Okanogan River from about RM 5 (just upstream of the sharp grade break) to approximately river mile 11.3 (the upstream extent of the "with Project" model).

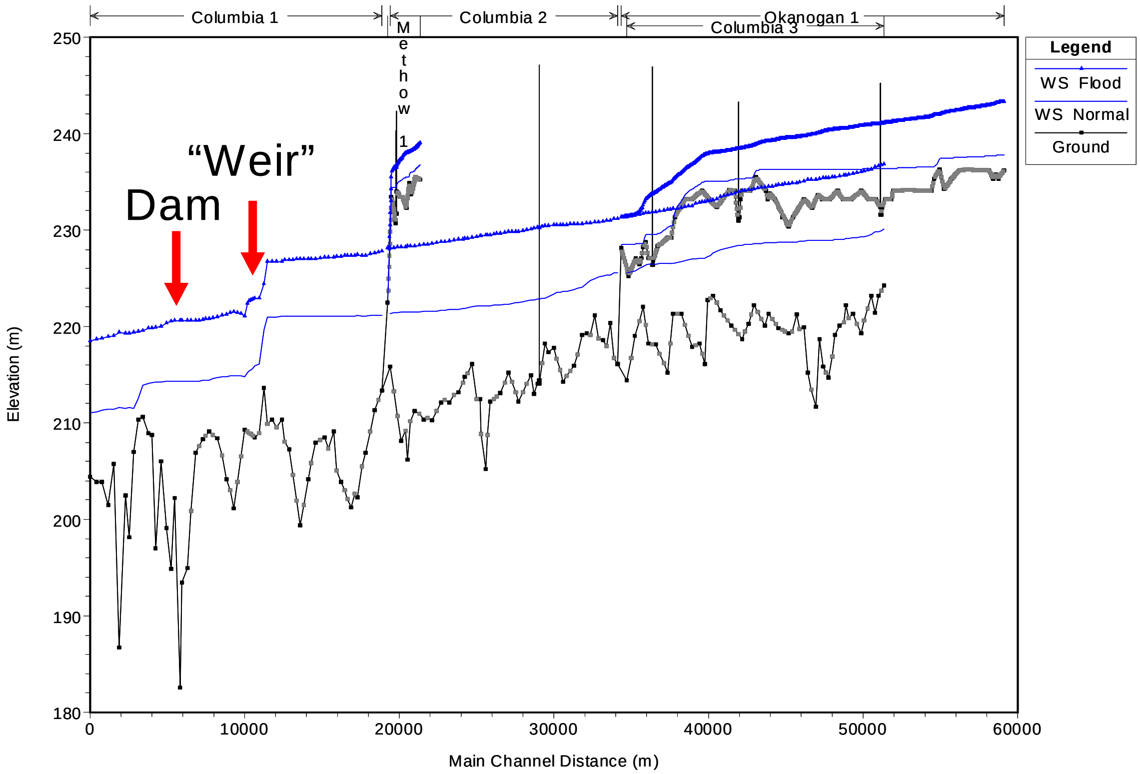

Figure 5.2-9 HEC-RAS Profiles of "Without-Project" Conditions.

Results from the HEC-RAS "without-Project" model (GeoEngineers, 2008) for flows in the Okanogan River on the order of 11 m^3/s (390 ft^3/s) indicate velocities in the lowest five miles of the Okanogan River on the order of 0.6 m/s (2 ft/s). This indicates that flows would take less than four hours to travel through this lowest five miles of the Okanogan River to reach the Columbia River. As the lowest five miles are relatively steep and generally shallow, they would be difficult to include in the larger "without Project" W2 model. As the travel time through this reach is relatively short, it was decided to not include it in the model for the results at RM 5 will be characteristic of conditions throughout the lowest five miles of the Okanogan River.

Aside from adjusting the values in the "dynamic shading" file to represent different angles for the sun to penetrate to the lowered "riverine" water surface elevations, all other input files remained the same as for the "with Project" model. The model was run for the same time period as the "with-Project" W2 model so that the results could be directly compared.

6.0 COMPARISON TO WATER QUALITY CRITERIA

The W2 models for “with Project” and “without Project” conditions were run for the nearly two years of simulation (1/1/2006 to 9/30/2007), and the results written each hour as depth-averaged temperatures. The results were saved at five “compliance point” locations (see Figure 6.1-1), and at other locations to evaluate system processes:

- Erlandsen’s
- Brewster Bridge
- Wells Forebay
- Wells tailrace
- Lower Okanogan (about RM 5)

The results were reported at RM 5 in the lower Okanogan River, because this is the downstream limit of the “without Project” model. It is located at the upstream end of the final steep section of the Okanogan River before it enters the Columbia River, and is representative of the reach not influenced directly by mixing between Okanogan River and Columbia River waters under “with Project” conditions.

The hourly results were post-processed to calculate daily maximum values. Then these maximum values were averaged over seven days (including the three days before and three days after) to calculate the 7-DADmax values at each location.

6.1 “Compliance Point” Comparisons

Figure 6.1-2 through Figure 6.1-6 show the “with Project” and “without Project” 7-DADMax values and their differences at the five locations in the Columbia River and Okanogan River (Figure 6.1-1). The maximum differences are summarized in Table 6.1-1. The results show that there are no “exceedances” of 0.3^{o}C at the four locations in the Columbia River. The results at RM 5 in the Okanogan River show a maximum difference of 1.1^{o}C, and exceedances of 0.3^{o}C occur on about five percent of the days. However, one significant problem when comparing “with Project” and “without Project” conditions is that the water moves through each system at different speeds. Therefore, if a pool of warm water is released from Chief Joseph Dam, it would reach Wells quicker if the dam were not there (i.e., under “natural river” conditions). This is especially true of the lower Okanogan River during the low-flow summer months, which is backwatered from Wells Dam. Thus, comparing the same time periods between “with Project” and “without Project” model results may not be an appropriate way to analyze Project effects on water temperature, due to differential flow velocities causing the same inflow waters to arrive at the compliance points at different times.

Another way to evaluate the results with regard to water quality temperature standards would be to compare the temperature exceedance distributions at each location, and evaluate their differences. Figure 6.1-7 through Figure 6.1-11 show the temperature exceedance distributions at each of the five locations in the Columbia River and Okanogan River, and the maximum differences are reported in Table 6.1-1. At each location, the maximum differences between the distributions did not exceed 0.15^{o}C, including at RM 5 in the lower Okanogan River. As depicted in Figure 6.1-6 and Figure 6.1-11, there is a balancing of heating and cooling in the lower Okanogan River that results in almost identical exceedance distributions. Figure 6.1-6 also shows the tendency for the temperatures “with Project” to be reduced as compared to “without Project” by about 0.5°C during the hottest summer months.

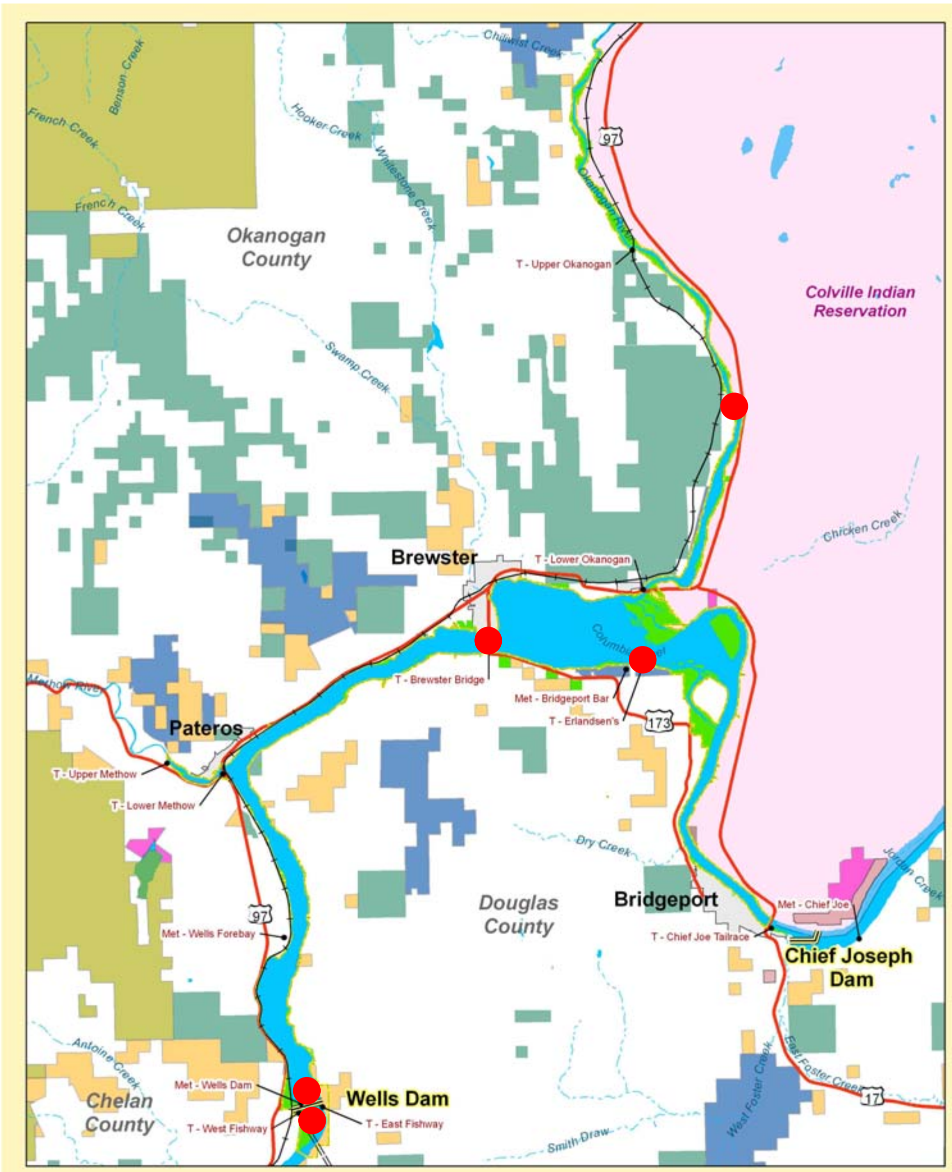

Figure 6.1-1 **Water temperature model “Compliance Point” Locations.**

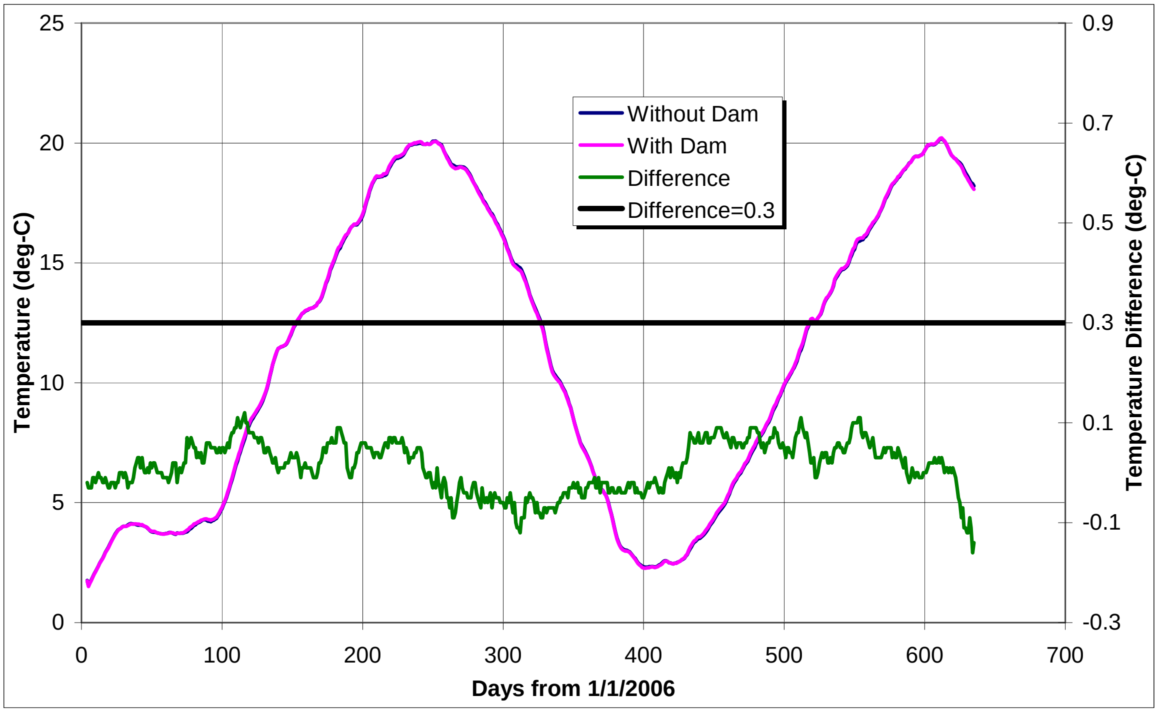

Figure 6.1-2 Comparison of 7-DADMax at Erlandsen's.

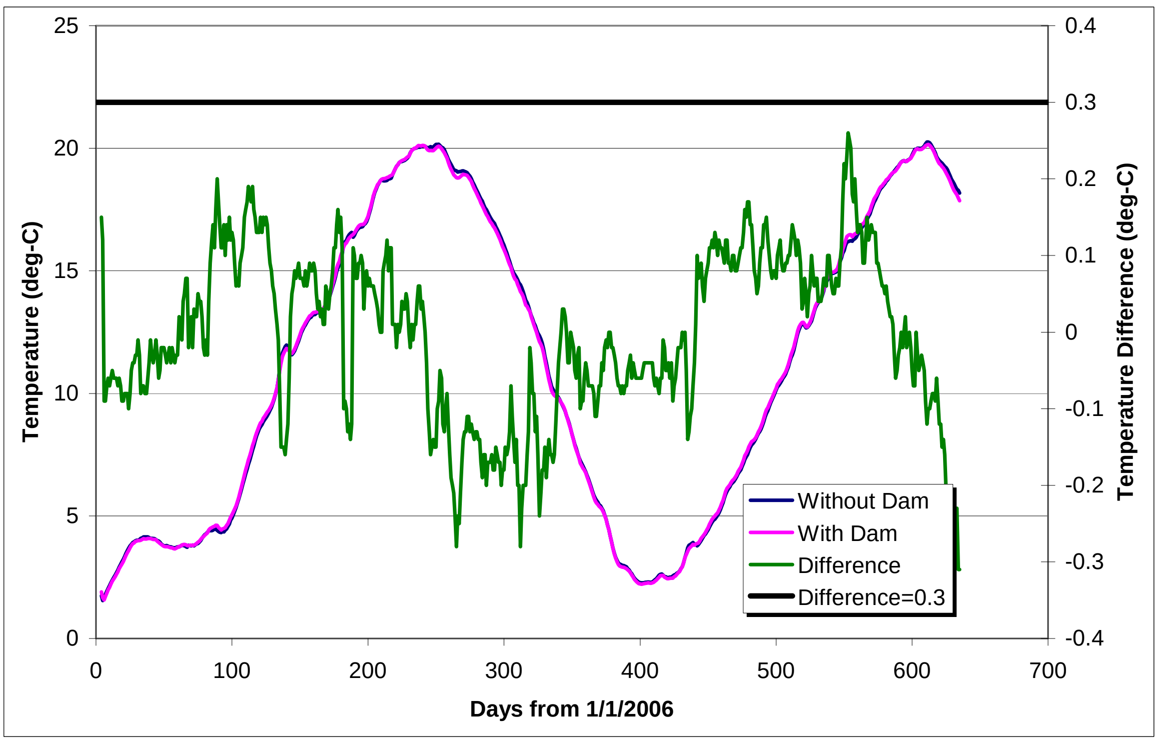

Figure 6.1-3 Comparison of 7-DADMax at Brewster Bridge.

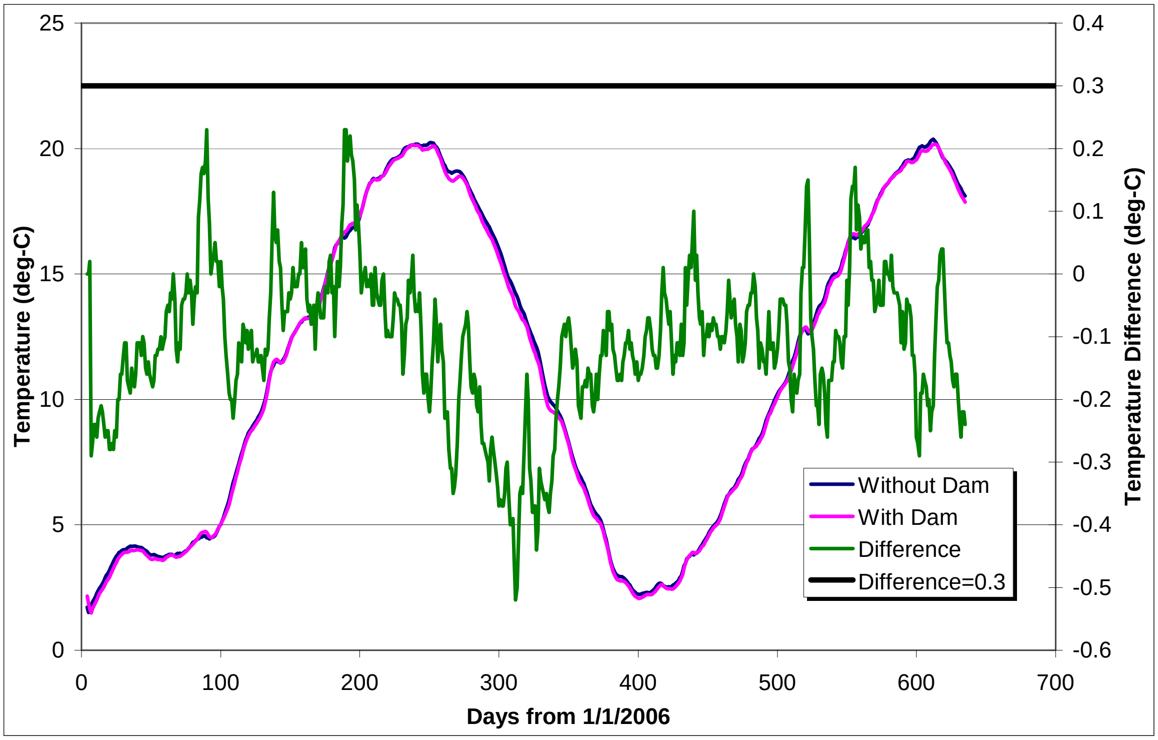

Figure 6.1-4 Comparison of 7-DADMax at Wells Forebay.

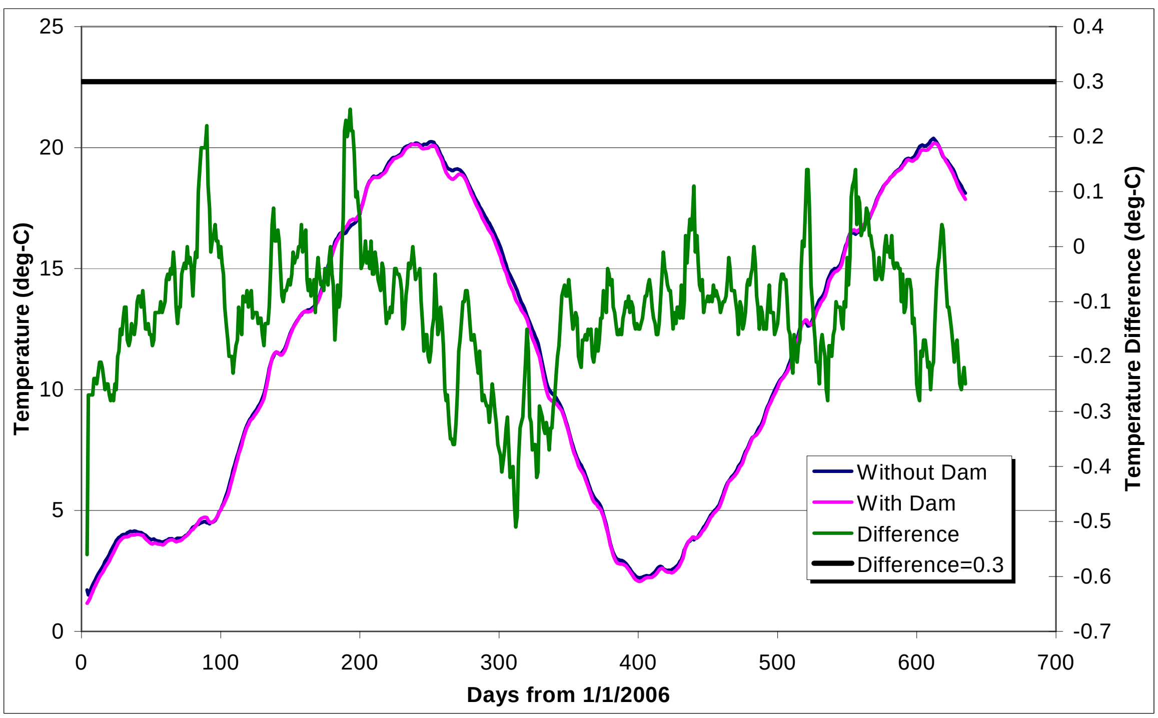

Figure 6.1-5 Comparison of 7-DADMax at Wells Tailrace.

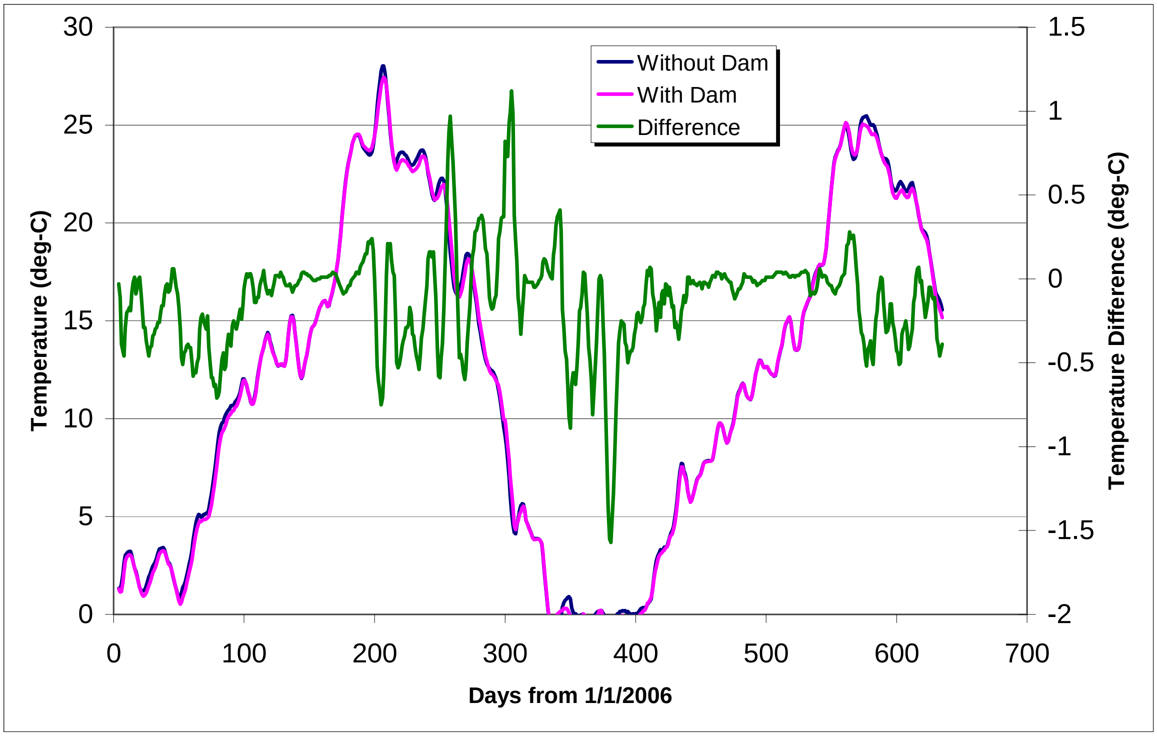

Figure 6.1-6 Comparison of 7-DADMax at Okanogan RM 5.

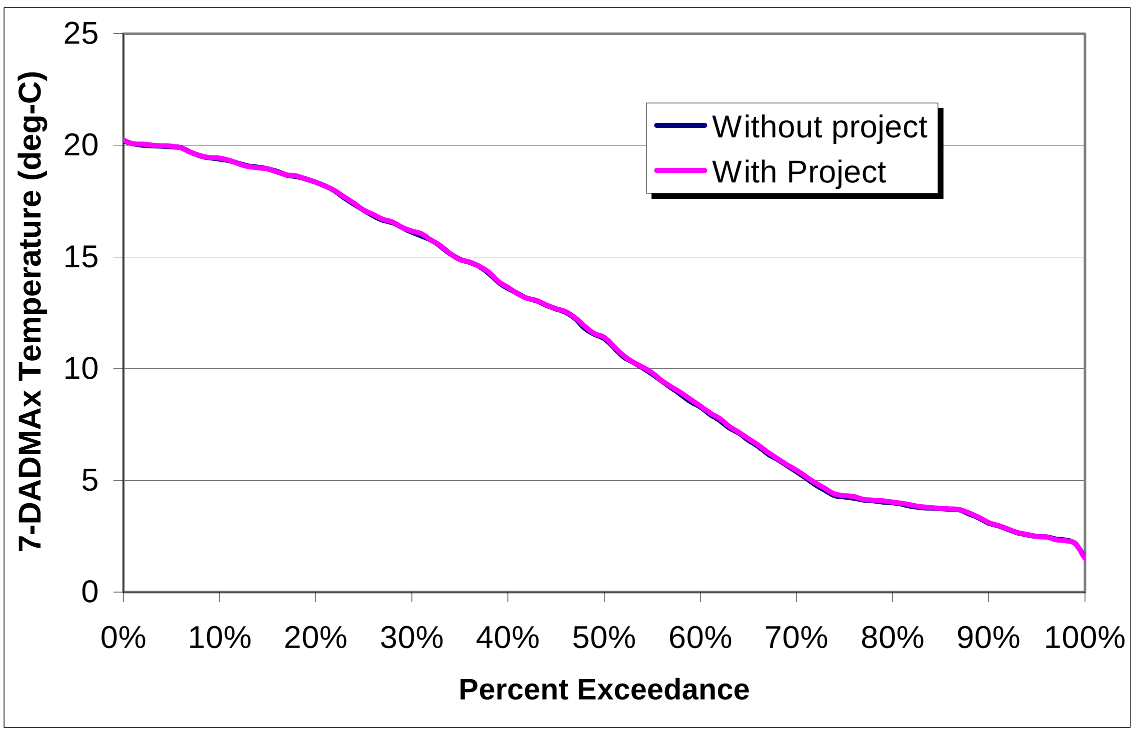

Figure 6.1-7 Comparison of Exceedance Frequencies at Erlandsen's.

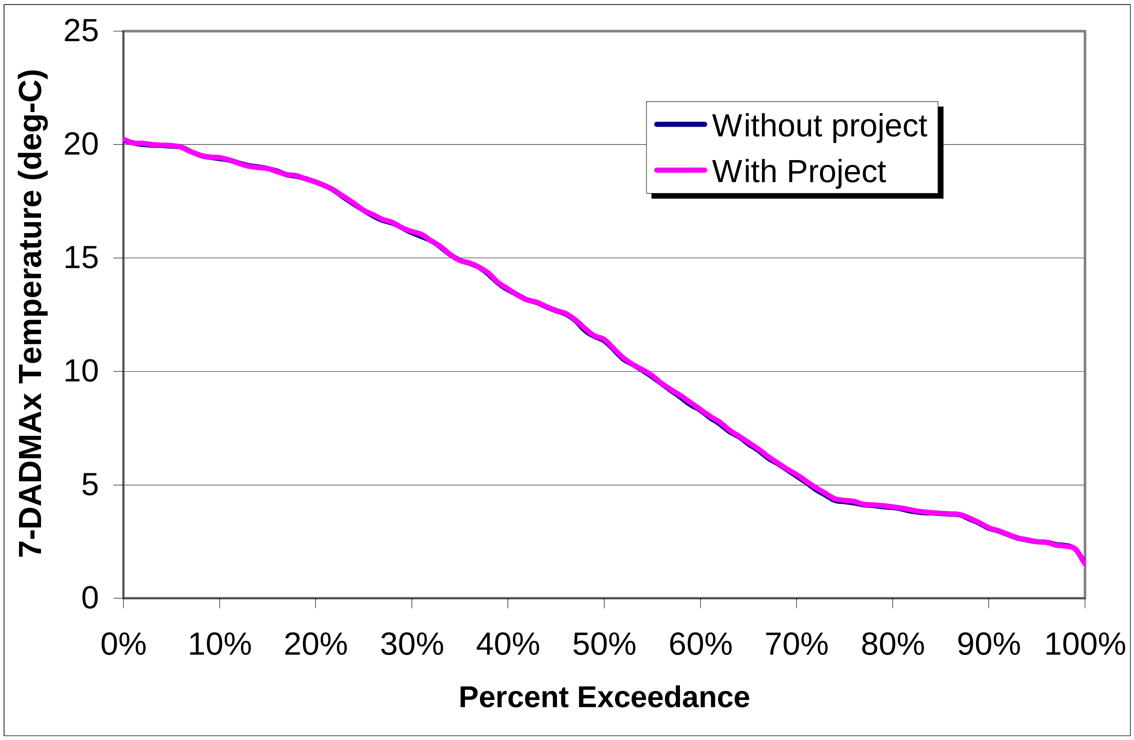

Figure 6.1-8 Comparison of Exceedance Frequencies at Brewster Bridge.

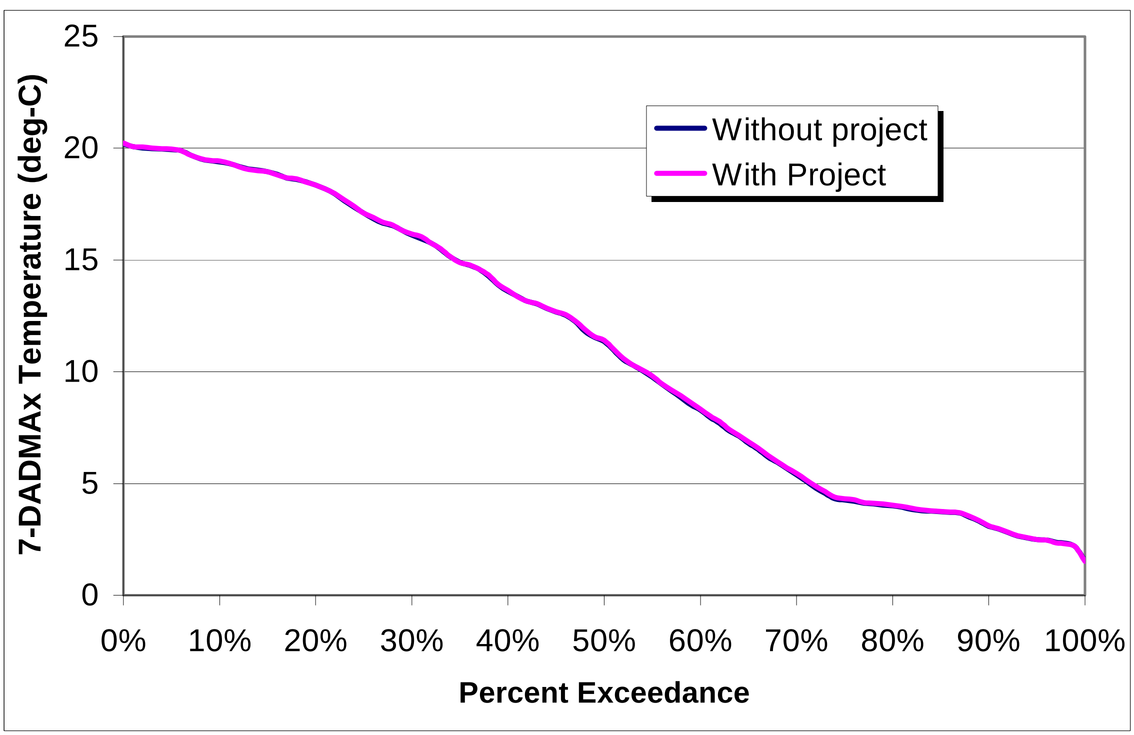

Figure 6.1-9 Comparison of Exceedance Frequencies at Wells Forebay.

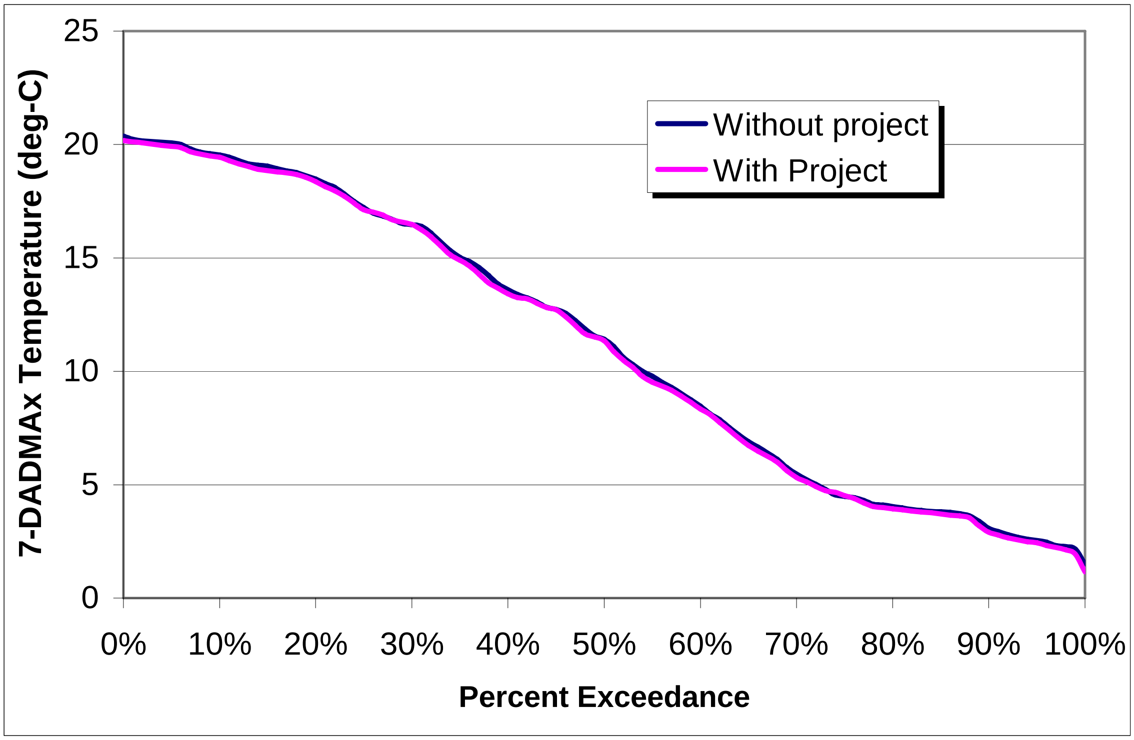

Figure 6.1-10 Comparison of Exceedance Frequencies at Wells Tailrace.

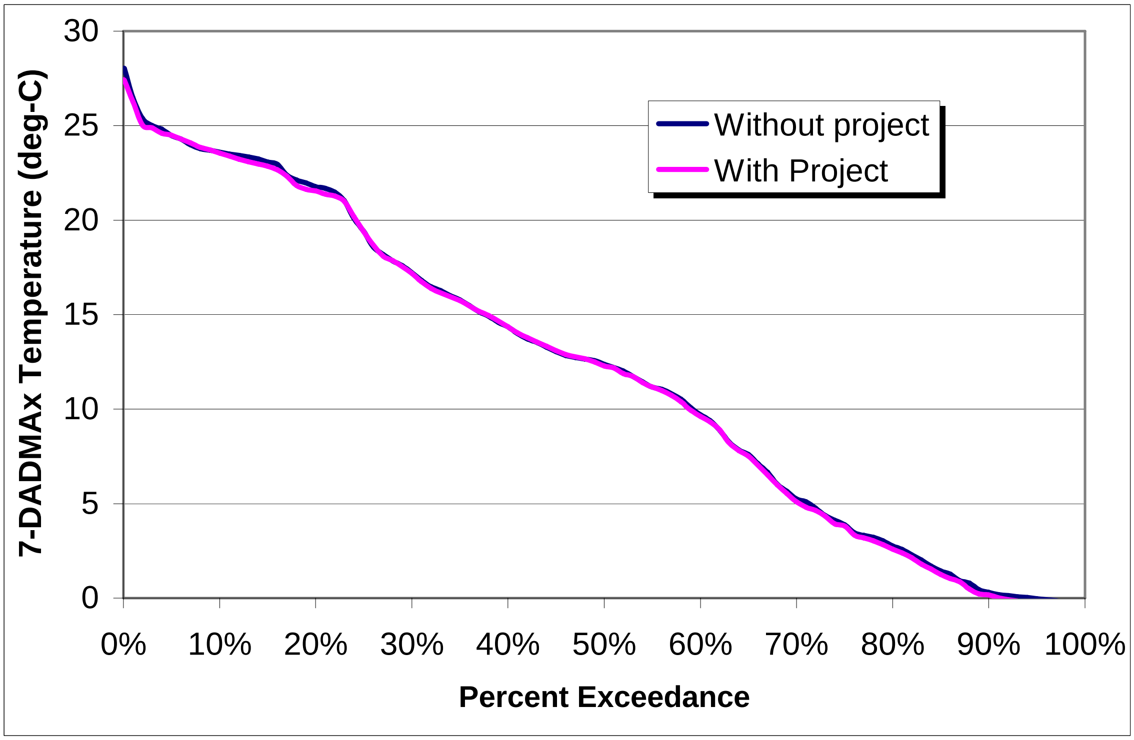

Figure 6.1-11 Comparison of Exceedance Frequencies at Okanogan RM 5.

Table 6.1-1 Comparison of Maximum Temperature Differences.

Location	Percent of days with difference exceeding 0.2(^{o}C)	Maximum 7_DADmax difference (^{o}C)	Maximum Exceedance difference (^{o}C)
Erlandsen's	0	0.12	0.08
Brewster Bridge	0.9	0.26	0.15
Wells Forebay	0.8	0.23	0.11
Wells Tailrace	1.3	0.25	0.12
Okanogan River (RM 5)	(see text)	1.12	0.10

6.2 Mixing in the Lower Okanogan River

Figure 6.2-1 shows the "with Project" 7-DADMax temperatures at locations in the lower Okanogan River. Also shown are the temperatures released from Chief Joseph. In the lower Okanogan River, especially below the SR 97 Bridge, there is significant mixing with Columbia River water. During the very hot summer months, the releases from Chief Joseph are significantly cooler than the very warm temperatures upstream in the Okanogan River. During the winter months, the releases from Chief Joseph may be significantly warmer than the temperatures in the Okanogan River and serve to reduce ice formation. During the spring months, relatively little effect is seen, as this is a period of high snowmelt runoff in the Okanogan River. The most pronounced effect is during very short periods in the fall months when the Okanogan River cools more rapidly than the releases from Chief Joseph and the Okanogan River flows remain low.

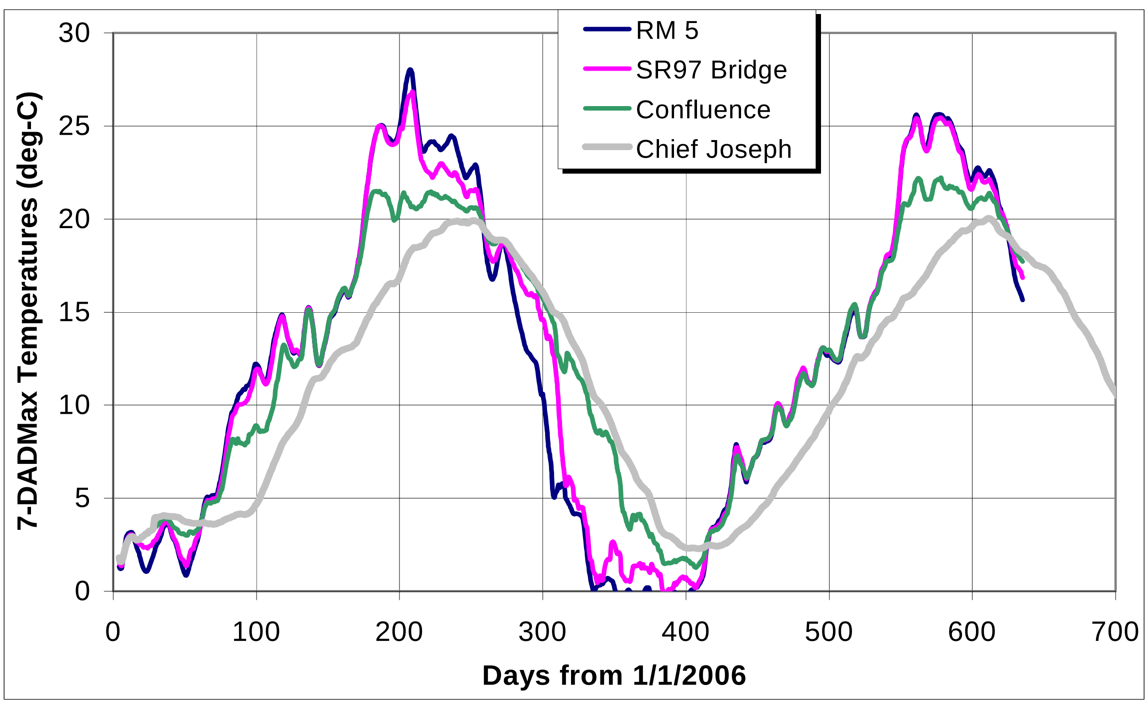

Figure 6.2-1 Comparison of 7-DADMax in Lower Okanogan River.

To examine these temperatures more closely, to determine whether they are influenced by (1) the backwatered flow moving slowly towards the Columbia River heating up more than 0.3^{o}C due to thermal heating, or (2) whether this was simply mixing of the two water bodies at different temperatures, the data were processed to look for conditions with (1) Okanogan River ("without Project") temperatures exceeding 17.5^{o}C, (3) downstream temperatures exceeding upstream temperatures by more than 0.3^{o}C, and (4) the downstream water being warmer than temperatures in the Columbia River. 17.5^{o}C was selected because it represents the threshold temperature for salmon rearing and migration (Ecology 2006). The analysis used the "without Project" modeled temperatures at RM 5 as ambient conditions, assuming that these temperatures would remain relatively uniform along the lower five miles of this steep section of the Okanogan River.

The analysis of the results for 2006-2007 showed only three days on which these conditions occurred, with the largest increase above Columbia River temperatures being 0.24^{o}C. All of the differences occurred during late September when the flows in the Okanogan River were low and would have been caused by thermal heating in the lowest few miles of the Okanogan River. The analysis neglected any warming in the Columbia River between Chief Joseph and the Okanogan River confluence. Therefore, it is clear that whether the origin of the water is from the Okanogan River or from the Columbia River, thermal heating does not cause the ambient water temperature to increase more than 0.3^{o}C.

6.3 Mixing in the Lower Methow River

Figure 6.3-1 shows time histories of the RM 1.5 observations, the results of the "with Project" model at the SR 97 Bridge, and the temperatures released from Chief Joseph. The results show processes very similar to those discussed in the lowest 1-2 miles of the Okanogan River. In the winter months, the very cold flows in the Methow River are moderated by warmer releases from Chief Joseph. In the hottest summer months, the high temperatures observed at RM 1.5 are moderated by cooler backwater from the Columbia River, and may cool the lower Methow River by 2-3^{o}C. In the fall, backwater from the Columbia River may intrude into the lower Methow River and mix with the more-rapidly cooling but generally low flows in the Methow River.

The next step in the model including processing the data to look for conditions with (1) Methow River ("without Project") temperatures exceeding 17.5^{o}C, (2) downstream temperatures exceeding upstream temperatures by more than 0.3^{o}C, and (3) the downstream water being warmer than temperatures in the Columbia River. 17.5^{o}C was selected because it represents the threshold temperature for salmon rearing and migration (Ecology 2006). The analysis of the results for 2006-2007 showed only seven days on which this thermal heating condition occurred, with the largest increase above Columbia River temperatures being 0.3^{o}C. All of the differences occurred in July-September when the flows in the Methow River were relatively small. Again, the analysis neglected any warming in the Columbia River between Chief Joseph and the Methow River confluence. Whether the origin of the water is from the Methow River or from the Columbia River, thermal heating does not cause the ambient water temperature to increase more than 0.3^{o}C.

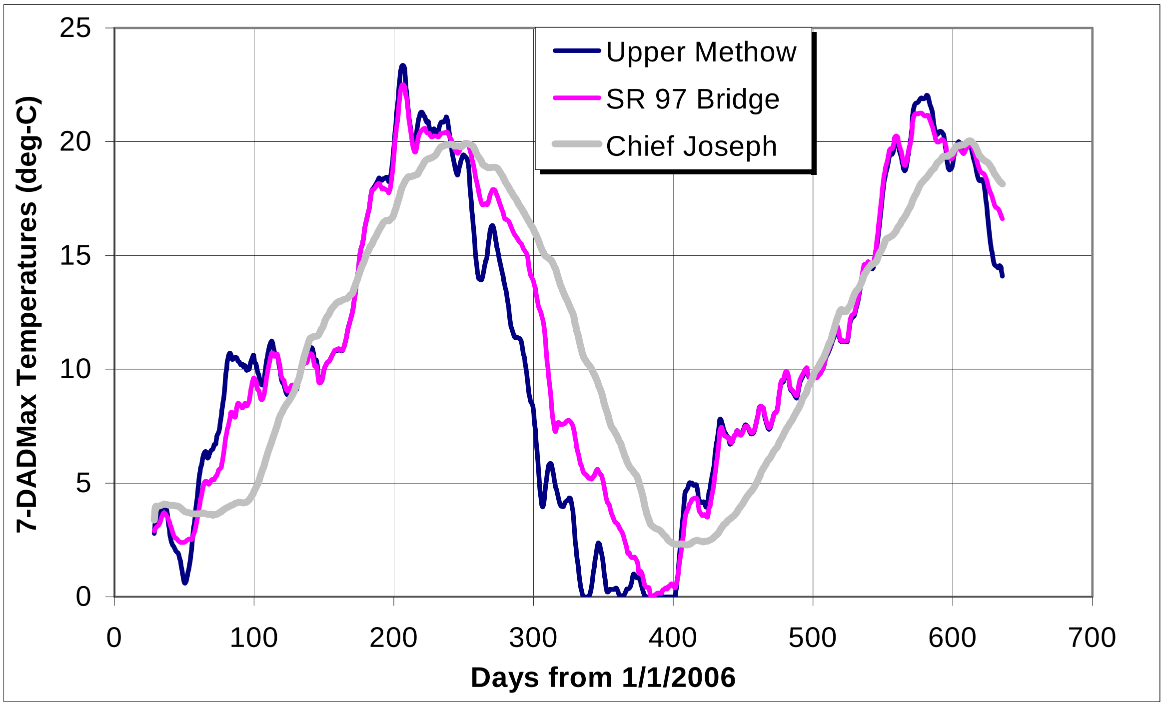

Figure 6.3-1 Comparison of 7-DADMax in Lower Methow River.

7.0 DISCUSSION AND CONCLUSION

Ecology must assess Wells Project compliance with State water temperature criteria, and determine whether the Project causes the 7-day average of maximum daily water temperatures (7-DADMax) to increase significantly compared to "without Project" conditions. When the waterbody's temperature is naturally greater than maximum values recommended for various classes of aquatic life (Ecology, 2006), or within 0.3°C of those values, then the Project should not cause the temperatures to increase by more than 0.3°C. This report presents the development and calibration of a "W2" model of the Wells Project ("with Project" model), and the development of a second W2 model of "without Project" conditions, to examine the change in temperatures within the Project's boundaries. The results of the model were processed to calculate the 7-DADMax for each day of the simulation period, 2006-2007. The results demonstrate that the Wells Project does not cause increases over "ambient" temperatures that exceed 0.3°C.

The simplest way to evaluate temperature changes within the Project is to analyze the model results and identify increases of more than 0.3°C over the ambient ("without Project") conditions. Time histories and exceedance distributions were compared at five "compliance" points. None of the four locations along the Columbia River had temperature increases that exceeded 0.3°C in either the time histories or the exceedance distributions. While the location at RM 5 in the lower Okanogan River had one occurrence of a maximum 7-DADMax temperature increase of 1.1°C, occurring under unique weather and flow conditions and when modeled "without Project" river temperatures were about 17.5°C, the maximum difference in the exceedance distributions was only 0.1°C. This shows that while there may be short-term differences in temperatures, where the occurrences of high temperatures may be influenced by the slower downstream movement of Okanogan River water due to the backwater from Wells Dam, the overall temperature regime at this location is essentially the same.

In the Okanogan River, upstream of approximately RM 5, the river is moderately influenced by backwater conditions from the Columbia River. A comparison of observed temperatures at Malott (RM 17) and Wakefield Bridge (RM 10.5) shows that, in general, backwater from Wells Dam creates a deeper pool that tends to reduce the very high upstream summer temperatures found farther upstream in the free flowing Okanogan River. The daily high temperatures within the inundated portions of the Okanogan River were often lowered relative to the daily high temperatures upstream of the Project during the hottest summer months.

The lowest 1-2 miles of the Okanogan River are influenced by the intrusion of Columbia River water. This too has the significant effect of reducing summer high temperatures by 2-6°C, and increasing winter temperatures 1-3°C, reducing the extent and length of freezing. In the fall months, as the Okanogan River temperatures drop more quickly than those in the Columbia River, the lowest 1-2 miles of the Okanogan River may see fall increases of about 1°C, as Columbia River water intrudes into the lower Okanogan River during a period when flows in the Okanogan River are quite small. However, additional analyses indicate that while backwater from the Columbia River does tend to slow the speed of the Okanogan River, the additional thermal "exposure" does not cause increases in temperatures of more than 0.3°C. Rather, the differences in the lower river temperatures are a result of Columbia River water intruding into the lower Okanogan River and not warming of Okanogan River water.

The processes in the lowest 1.5 miles of the Methow River are similar to those in the lower Okanogan River. While the summer high temperatures in the Methow River (they can reach 24°C) are not as high as those upstream in the Okanogan River, backwater from the Columbia River still reduces the summer high temperatures by about 1°C and increases the winter temperatures by 2-3°C, reducing the extent and length of freezing. In the fall months, as the Methow River temperatures drop more quickly than those in the Columbia River, the lowest 1.5 miles of the Methow River may see fall increases of about 2-3°C, as Columbia River water intrudes into the lower Methow River during a period when flows in the Methow River are quite small. Again, additional analyses indicate that while backwater from the Columbia River does tend to slow the speed of the Methow River, the additional thermal "exposure" does not cause increases in temperatures of more than 0.3°C. Rather, the differences in the lower river are attributed to the mixing of Columbia River and Methow River waters within the geographic confines of the lower Methow River.

8.0 STUDY VARIANCE

There were no variances from the FERC approved study plan for the Water Temperature Study.

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